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CHEMICAL HEAT PUMP STUDY

FINAL REPORT

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Supply and Services, Canada

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by

Delta Projects Inc.

2494.CP

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1.0 SUMMARY

A Chemical Heat Pump application has been optimized in an attempt to obtain an economic installation in the petrochemical industry.

Potential vendors were contacted to determine their interest in bidding on a lithium-bromide installation at the host company, Polysar (Corunna). Vendors were not prepared to bid on the application chosen due to the high temperature, even though this was less than the recognized maximum temperature of 165°C.

A new absorption fluid consisting of a tertiary nitrate is described and a design formulated in order to review the economics of the process. (Appendix C). The heat pump using this fluid will be referred to in this report as the High Temperature Chemical Heat Pump.

A payout of four years was obtained when using typical industry steam costs, but this payout is in excess of fifteen years when Polysar (Corunna) steam costs and conditions are used in the analysis.

Comparisons between the two common types of heat pump indicates that the installed cost of the mechanical heat pump is three times higher than that for the chemical heat pump when compared on the same basis.

The High Temperature Chemical Heat Pump can be an economic option for energy conservation applications and some industrial applications. It will provide higher temperature lifts and work at higher temperatures than previously permissable with lithium-bromide. Integration of the heat pump in the grass-root design of the plant will also increase the viability of this system.

1.1 INTRODUCTION

Absorption Systems are widely used in industrial refrigeration cycles and domesti.· propane driven refrigerators, but their use in North America for chemical pump applications are rare.

An earlier study (Chemical Heat Pump - Phase 1, Stearns Catalytic, 1984) had considered a lithium-bromide heat pump installation on a toluene recovery tower at the Sunoco refinery in Sarnia, and determined the payout to be 3.5 years using steam costs of $7.50/1000 lbs. ($16.5/1,000 kg). While this payout did not meet Suncor's target of 3 years usually used to screen energy conservation cases, equipment prices obtained during the study were U.S. sourced and considered high.

This phase of the study was initiated to develop a more detailed basis for design and cost estimates. To this end, a new host was obtained and a potential application chosen. Polysar (Corunna) agreed to host this study, and all qualified vendors were screened to determine their interest and capability.

2.0 PROCESS DESCRIPTION

2.1 Introduction

The principle of the Chemical Heat Pump has been well known for many years, with either ammonia/water or lithium bromide/water working fluids.

Increased energy prices in the 1970's led to a variety of energy conservation techniques, with the mechanical heat pump being among the most well known due to its popularity in the domestic heating market. Some key drawbacks to this type of mechanical compression cycle are the compressor, with its complex control systems, unstable operation and high cost. In addition, compressors for the heavy process industries are manufactured by a limited number of vendors, none of whom are located in Canada, with consequent loss of business to Canadian suppliers.

2.2 Chemical Heat Pumps

Chemical heat pumping is achieved by utilizing the heat of solution released when the absorption solution is diluted with the working fluid at a pressure which provides the required temperature. A closed cycle for regeneration/evaporation of both absorption solution and working fluid is used.

Chemical heat pumps are simple, closed circuit systems, that utilize heat exchangers and pumps to "pump" heat from lower to high temperature levels. Coefficient of Performance (COP) factors up to approximately 1.6 make these systems amenable to energy conservation applications, where suitable temperature levels are available.

Chemical heat pump applications were investigated in the United States by the Batelle Memorial Institute, who tested the feasibility of an elevated temperature operation for use in energy conservation.

The lithium bromide/water system was tested for upper temperature limits based on acceptable corrosion of carbon steel and copper alloys only, as stainless steels experienced stress cracking inherent with halides.

Batelle licensed this technology to Adolph Coors, and limited the upper temperature level of recovered heat to 200°C (392°F). Japanese vendors (Hitatchi Zosen and Sanyo) use 165°C (330°F) as the limit for their lithium bromide systems. While these temperatures provide adequate leeway for district heating and food processing applications, petrochemical plants have few such low temperature options.

2.3 High Temperature Applications

The need for higher temperature led to research into other absorption fluids, resulting in the selection of a tertiary nitrate salt coupled with water, patented by Energy Concepts Co.

An upper temperature limit of 260°C (500°F) has been set for this system, and is suitable for use with carbon steel.

Energy Concepts Co. have licensed this high temperature process to Litwin Engineers and Constructors Inc. who provided a detail design and layout of the proposed installation.

2.3.1 Cycle Description

The absorption solution used in this study is a tertiary nitrate salt consisting of a mix of lithium, potassium and sodium nitrates and uses water as the working fluid. The solution is non-toxic, stable, non-flammable and non-corrosive.

Optimum conditions have been set to simplify design choices and include heat exchanger approaches of 5.5°C (41.9°F), 3% nitrate solution concentration difference, a 5.5°C margin from crystallization and a 260°C (500°F) solution temperature limit.

Two variations of the basic concept are used depending upon the application chosen. The two variations discussed have significantly different COP's (e.g. 0.42 vs 1.6); depending on the temperature lift desired and applications.

2.3.1.1 Heat Amplifier

Refer to the Heat Amplifier Applicability Diagram (Figure 1), Temperature Amplifier Applicability Diagram (Figure 2), and the Duhring Diagram and Process Flow Sheet (Figure 3) in this section for the description that follows:

- This cycle is also known as "Type 1" or "Forward Absorption Heat Pumping" (FAHP) and allows low temperature heat to be elevated to a limited degree.

- The concentrated nitrate solution is diluted with water in the Absorber (A) at pressure suitable to provide the output heat at the required temperature. Figure 3 indicates conditions of 84.46 kPa(a) and 154.4°C in this exchanger for a typical case.

- The dilute nitrate solution is pumped to the Generator (G) or Desorber where water is evaporated by the regeneration medium. Conditions of 535.74 kPa(a) and 247°C were set in this example. The nitrate solution concentrations range between 83 and 86 wt.% in A and G respectively.

- A recuperator is located between the hot dilute and cool concentrated solutions and results in a small increase in efficiency.

- Water vapour from the Generator (G) provides additional output heat in the Condenser (C) at 535.74 kPa(a) and 154.5°C and flows in the Evaporator (E) where it takes up the low temperature heat at 84.46 kPa(a) and 95°C.

- A Coefficient of Performance (COP) of 1.64 is typical of this cycle with temperature lifts of up to 60°C at waste heat temperatures of 80°C. The variation in temperature lifts results from the limitations imposed by the Duhring Diagram plot.

2.3.1.2 Temperature Amplifier

Refer to the Useful Temperature Lift Diagram (Figure 2), and the Duhring Diagram (Figure 4) and Process Flowsheet Figure 5 (Item 3.12), in this section for the description that follows:

- This cycle is also known as "Type 2" or "Reverse Absorption Heat Pumping" (RAHP) and allows the temperature of a stream to be elevated by a significant amount at reduced efficiency.

- The concentrated nitrate solution is diluted with water in the Absorber (A) at a pressure suitable to provide the output heat at the required temperature. Figure 4 indicates conditions of 703.29 kPa(a) and 253°C in this exchanger for a typical case.

- The dilute nitrate solution is pumped to the Generator (G) or Desorber where water is evaporated by the waste stream at the lower temperature. Conditions of 59.98 kPa(a) and 164°C were set in this example. The nitrate solution concentrations range between 87 and 90 wt.% in (A) and (G) respectively.

- A recuperator is located between the hot dilute and cool concentrated solutions and results in a 6% increase in efficiency.

- Water vapour from the Generator rejects cycle heat in the Condenser (C) at 59.98 kPa(a) and 86°C and flows to the Evaporator (E) where it takes up the low temperature heat at 710.185 kPa(a) and 164°C.

- A Coefficient of Performance (COP) of 0.42 is typical of this cycle with temperature lifts of up to 90°C at waste heat temperatures of 160°C. The variation in temperature lifts results from the limitations imposed by the Duhring Diagram plot.

2.4 Comparison with Lithium Bromide

The tertiary nitrate solution provides improved parameters for performance over that for lithium-bromide in three important aspects as follows:

2.4.1 Maximum temperature lift:

A maximum lift is possible of about 60°C for the nitrate solution versus 43°C for the lithium bromide solution as shown on the Heat Amplifier Diagram. Similarly, temperature lifts of 90°C and 50°C are possible for the two fluids using the Temperature Amplifier cycles. Lithium bromide temperature lifts are limited by solubility fields and corrosion problems.

2.42 Maximum solution temperature:

A maximum temperature of 260°C versus 165°C is set by the allowable corrosion rates.

2.4.3 Stainless steels cannot be used with Lithium-bromide due to halide stress corrosion.

2.5 Instrumentation and Controls

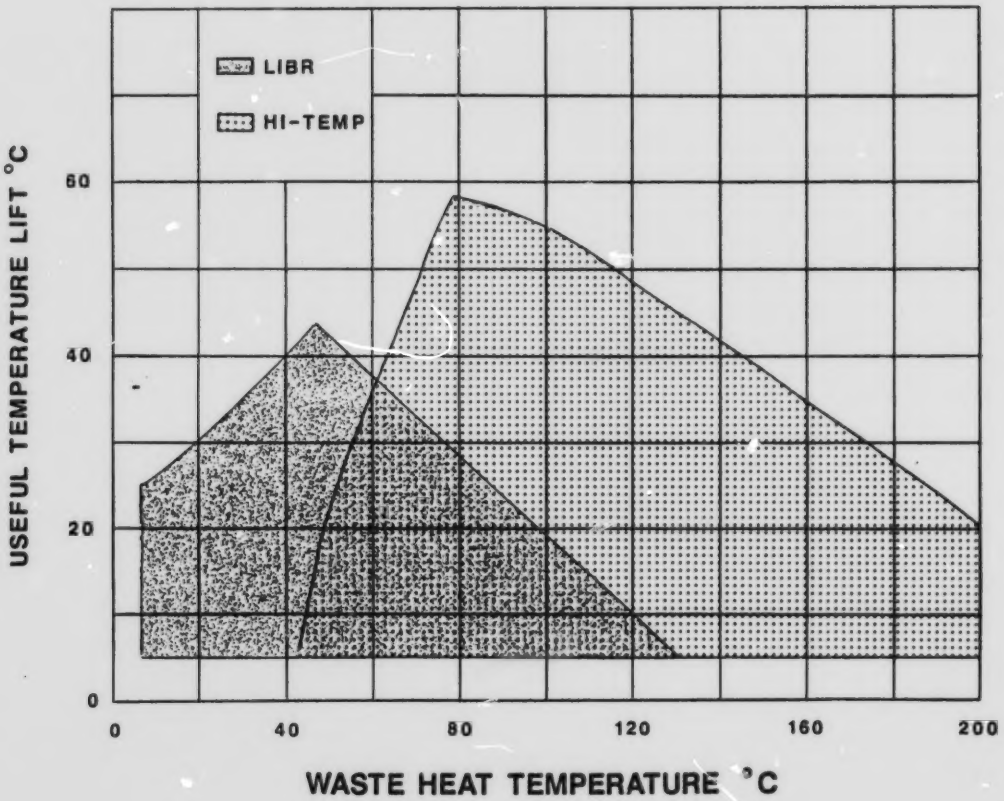
Control of the process is maintained by fixing the concentrated solution circulation rate, and balancing liquid inventory between the various heat exchangers by means of level control. Pressure buildup due to solution decomposition or air ingress to the system is controlled by a small vacuum pump which is operated, as required, to keep the condenser pressure between acceptable limits.

Steam used to provide the driving heat is controlled by the level of working fluid accumulated in the generator, as this is indicative of the inventory of the system.

CHEMICAL HEAT PUMP STUDY

HEAT AMPLIFIER APPLICABILITY DIAGRAM

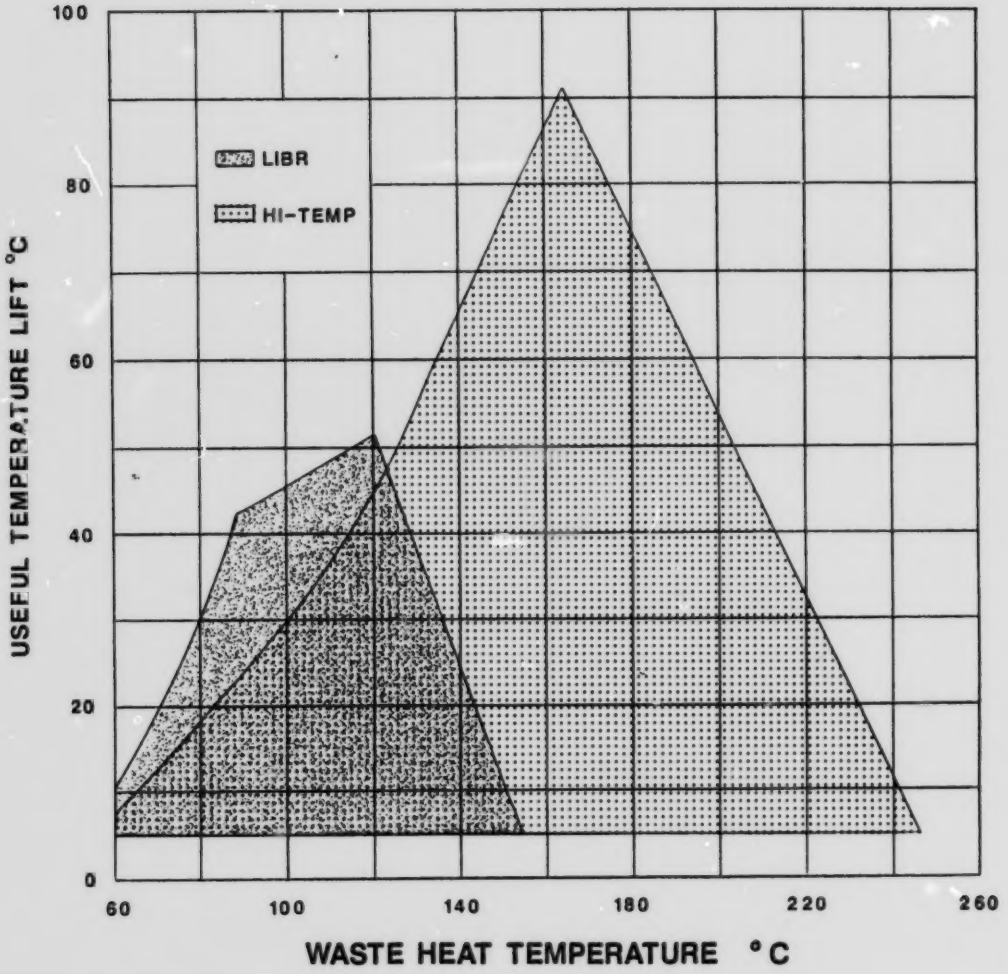
FIGURE 1



CHEMICAL HEAT PUMP STUDY

TEMPERATURE AMPLIFIER APPLICABILITY DIAGRAM

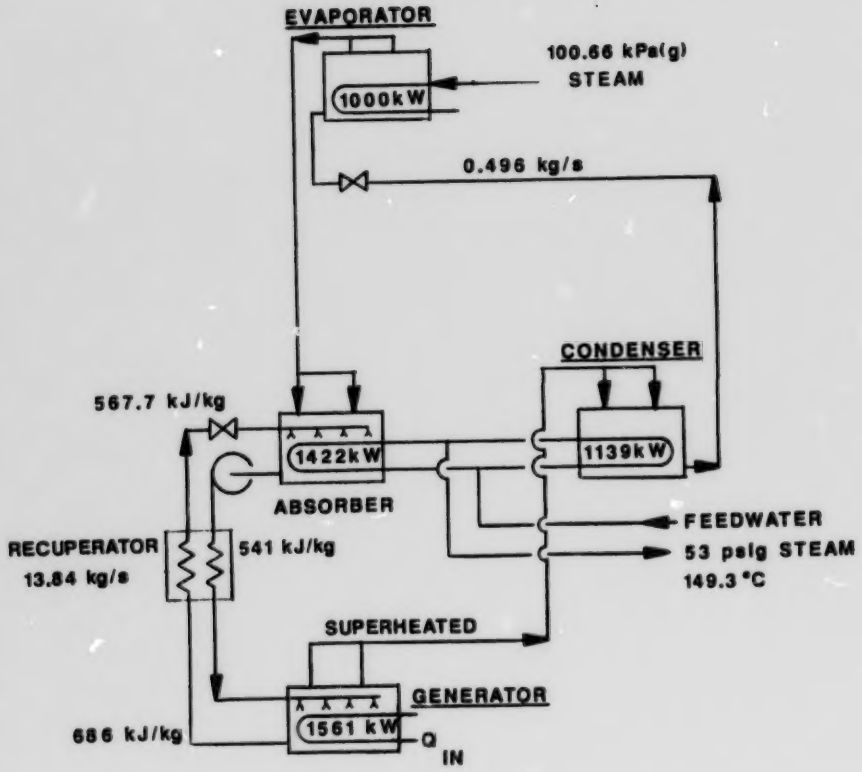
FIGURE 2



CHEMICAL HEAT PUMP STUDY

HIGH TEMPERATURE HEAT AMPLIFIER

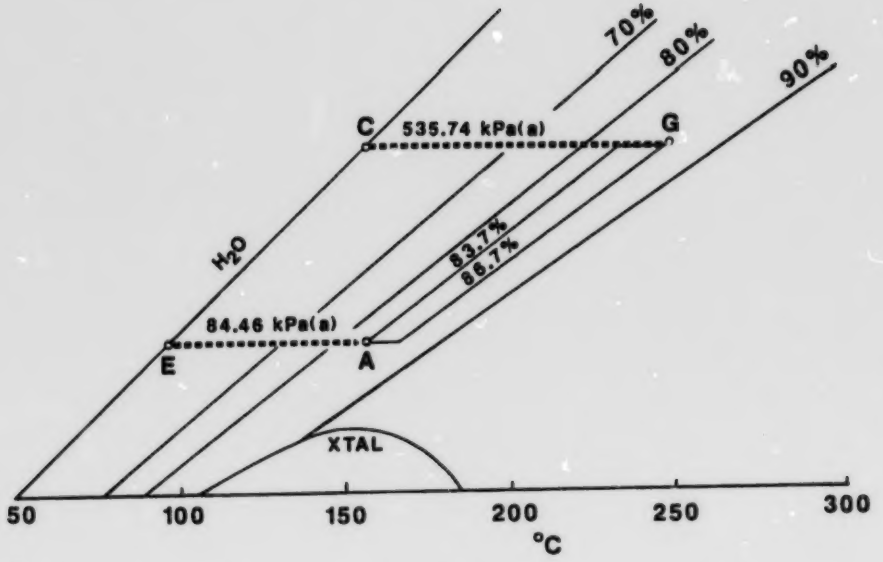
FIGURE 3



$$COP = \frac{QA + QC}{QG} = 1.64$$

COEFFICIENT OF PERFORMANCE- (COP)

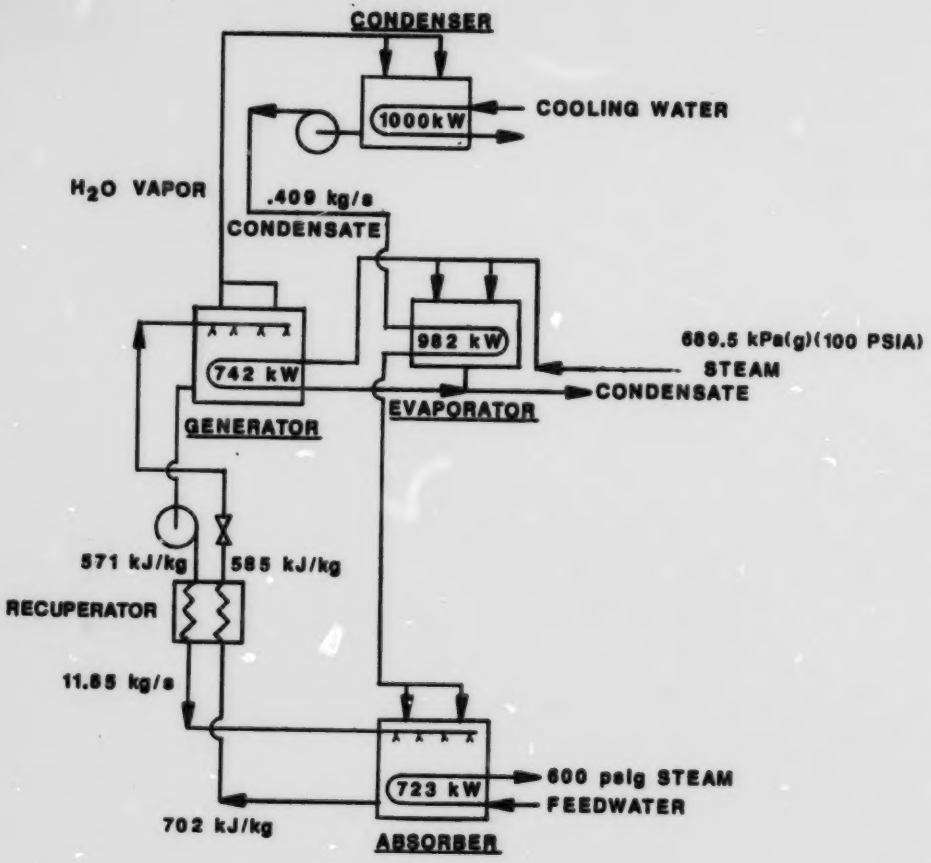
QA- ABSORBER OUTPUT
QC- CONDENSER OUTPUT
QG- GENERATOR INPUT

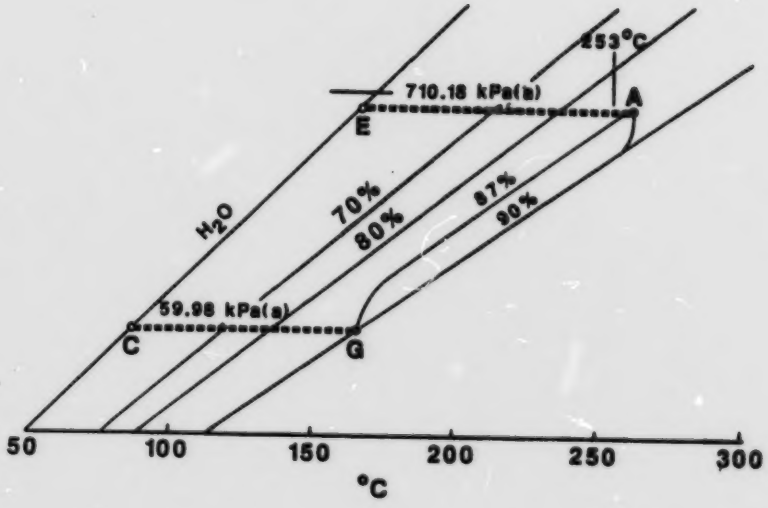


CHEMICAL HEAT PUMP STUDY

TEMPERATURE AMPLIFIER FOR HIGH TEMPERATURES

FIGURE 4





$$COP = \frac{QA}{QE + QG} = .42$$

COEFFICIENT OF PERFORMANCE- (COP)

QA- ABSORBER OUTPUT
QC- CONDENSER OUTPUT
QG- GENERATOR INPUT

3.0 DISCUSSION

3.1 Project Scope

A Chemical Heat Pump application was sought from among the processing industries in the Sarnia area in an attempt to develop a profitable installation in the petrochemical industry.

An earlier study (Chemical Heat Pump - Phase I, Stearns Catalytic, 1984) had considered a lithium-bromide heat pump installation on a toluene recovery tower at the Sunoco refinery in Sarnia, and determined the payout to be 3.5 years using steam costs of $16.53/1000 kg ($7.50/1000 lbs.). While this payout did not meet the target of 2 years usually used to screen energy conservation cases, equipment prices obtained during the study were United States sourced and considered high.

This phase of the study was initiated to develop a more detailed basis for design and cost estimates. To this end, a new host was obtained and a potential application chosen. Polysar (Corunna) agreed to host this study, and all qualified vendors were screened to determine their interest and capability.

3.2 Vendor Screening

An extensive list of probable chemical heat pump vendors, both in North America and Japan were contacted to determine their interest in proposing on an application chosen at the Polysar (Corunna) site.

An interim report of these contacts has been issued (Task 1 - Discussion with Heat Pump Vendors, Appendix A) and indicates that at the time of the survey, only 3 of the 18 companies contacted were prepared to respond to a proposal. The remaining vendors either offered only chiller systems or felt that there was insufficient market demand to warrant development.

The vendors who expressed interest include Litwin Engineers and Constructors Inc., Energy Concepts Co. as agents for Hitachi-Zosen, and Tokyo Sanyo Electric Company.

3.3 Initial Inquiry

An inquiry was developed based upon the lithium-bromide heat pump cycle arranged between two separate towers. A maximum process temperature of 159^{o}C was required and 4.68 MW (16.0 MM Btu/hr) of waste heat available for use. The inquiry is provided in Appendix B.

Although the case chosen met current temperature limits for the lithium-bromide cycle of 165^{o}C (330^{o}F), all vendors contacted declined to bid on this option.

Litwin, who had acquired the Batelle license from Coors, were committed to build and test their first unit before proposing on other installations.

Hitachi-Zosen declined on the basis that the maximum temperatures required exceeded their current limits for lithium-bromide systems. Corrosion was experienced at the 165^{o}C limit previously set, and reduced limits were imposed while the problem was being resolved.

Tokyo Sanyo did not submit a bid.

Based upon the above, it was Stearns Catalytic's recommendation to abandon lithium-bromide as an absorption fluid for this study due to the low temperature limits set which are of little use in a petrochemical facility, and instead review a new absorption fluid with higher temperature limits patented by Energy Concepts Company.

3.4 Technology License

The inquiry sent to the interested vendors specifically addressed the requirement to obtain a technology package rather than imported equipment, thus enabling detail design work and manufacturing to be carried out in Canada.

Energy Concepts and Litwin are the only vendors who have responded to this request as it pertains to the High Temperature absorption fluid described below, and have indicated that they would be willing to license selected companies to design and build equipment in Canada for a fee if the project appears feasible.

Litwin is a subsidiary of AMCA International, a Canadian company, owned by Canadian Pacific and previously known as Dominion Bridge Limited in Montreal.

3.5 High Temperature Absorption Fluid

A high temperature absorption fluid was seen as necessary to replace lithium-bromide in the chemical heat pump cycle so as to expand the amenable energy conservation market for this system.

Energy Concepts Co. embarked upon a test program sponsored by the U.S. Department of Energy to find an absorption fluid that would permit higher temperature limits than those in place for lithium-bromide.

This test program is well described in the article "500^{O}F Absorption Heat Pumping under Development" by W.F. Davidson and D.C. Erickson of the Energy Concepts Co. included in Appendix C.

A tertiary nitrate salt was determined to provide the optimum performance and consists of the nitrate salts of lithium, potassium and sodium in concentrations of 53 wt%, 28 wt% and 19 wt% respectively.

The tertiary nitrate can operate at temperatures as high as 260°C having physical properties that permit significantly higher temperature lifts than lithium-bromide (90°C versus 50°C in the Temperature Amplifier case). The absorption fluid is non-toxic, non-flammable, stable stable non-corrosive and enjoys the thermal benefits of both high heat transfer and a high Coefficient of Performance (1.64 in the Heat Amplifier case).

3.6 Application Screening

A number of applications were chosen for their potential energy saving at Polysar (Corunna) Limited, an integrated ethylene production facility located in Sarnia, Ontario.

Cycle conditions were chosen for 4 cases, and indices reflecting return on investment were calculated for each. The index used was a ratio of UxA/H where UxA is the product of heat exchanger heat transfer coefficient and area for all exchangers represents the major equipment costs used in the heat pump cycle. (H) represents the value of heat savings obtained based upon the price of heat used.

The low index will represent a high return on investment. UxA is used for equipment cost rather than (A) since UxA is obtained rapidly from the ratio Q/LMTD where (Q) is heat exchanger duty and LMTD is log mean temperature difference for each exchanger. (U) values obtained in the heat pump cycle are controlled by the absorption fluid, and are similar in all exchangers.

Indices obtained ranged between 0.248 and 0.396, with the selected option of 0.249 being the best choice as extended piping required in the low index case could not be allowed for.

The case chosen was a combination of Degum Tower Overhead heat driving Stripper Bottoms Reboiler. Details of this analysis are presented in Appendix D.

3.7 Heat Pump Inquiry

An inquiry was submitted to Energy Concepts Co. requesting a design and estimate for the selected case. Litwin Engineers and Constructors Inc. who are licensed by Energy Concepts to perform the engineering for these heat pumps supplied a Piping and Instrument Diagram (D-0010), a typical Skid Layout (SK-D-1500) and an estimate for the supply of the skid mounted heat pump. See Appendix E for details of this inquiry, the Piping and Instrument Diagram, and Skid Layout.

3.8 Installed Cost Estimate

An installed cost estimate was prepared to determine the return on investment for the High Temperature Absorption Fluid.

Canatara Engineering Ltd. was retained by Delta Projects Inc., formerly Stearns Catalytic, to provide a design and cost estimate for the installation including inter-connecting piping and power.

Equipment sizes and prices were obtained and a piping layout produced to confirm the skid size and allow a high confidence estimate to be produced.

A detailed installed cost estimate of $1,308,900 at +/- 10% confidence level was determined for this facility using vendor inquired prices and a detailed takeoff. This included a skid estimate of $763,000 with on-site installation requiring the balance.

Allowing a 10% contingency/fee for the skid manufacturer gives a figure of $839,300, which is approximately 40% less than the Energy Concepts/Litwin estimate of U.S. $843,100. However, the on-site installation costs are estimated to be approximately 35% of the total, which is twice the typical skid installation cost, and results from the remote location of one of the exchanger sets. This installation cost is usually factored and can lead to extremely low estimates.

The above estimate would apply to a typical petrochemical plant, and in the Polysar (Corunna) case, a high priced alloy is required for some of the process exchangers due to corrosion. This alloy requirement is not typical of the industry and thus an additional $208,000 applies.

The Estimate is included in Appendix F.

3.9 Return on Investment

A payout in excess of 15 years results for the Polysar (Corunna) case, and falls well short of an economic project. This results mainly from the extremely low cost for 1,379 kPa(g) steam obtained as extraction steam from turbines.

A return on investment has been calculated for petrochemical industry installation and the specific Polysar (Corunna) case used.

A payout of 3.9 years results for the typical case, and falls short of the 2 year payout threshold usually used for energy conservation projects. The current low steam price of $12.10/1000 kg. resulting from low crude oil prices of $\$2.86/m^3$ make an economic payout difficult to obtain. A steam price of $18.74/1000 kg. resulting from a return to previous high crude prices would make the chemical heat pump competitive for this particular application using standard materials. Integration of the installation in the grass-roots design would also improve the viability of the system.

The return on investment calculations are provided in Appendix G.

3.10 Cost Comparisons

Heat recovery techniques to save energy usually fall into two categories:

i) heat exchange
ii) heat pumping

Heat exchange uses surface area installed to transfer heat from higher temperatures streams to those at lower temperature. Heat pumping produces the reverse of these conditions.

Heat exchange includes both static surface area in shell and tube bundles, and dynamic surface area in rotating air preheater type units. Location of the exchanger is limited to an economic positive temperature driving force, and has been the topic of studies on "Pinch Analysis" by a number of workers including B. Linnhoff et al.

Heat pumping includes both chemical and mechanical types of heat recovery from a lower to a higher temperature level, and involves complex equipment arrangements compared to the simple heat exchanger. This complexity is reflected in the relative costs of the different categories, and comparisons between the heat pumping types, only, will be considered in this study.

Mechanical heat pumps rely on the principle of recovering the latent heat available in a process fluid by compressing and subsequently condensing the stream against a lower temperature fluid. Drawbacks include complex compressors with associated control systems and low pressure drop tower trays and exchangers to minimize compressor pressure ratio.

Maximum compressor discharge temperatures of approximately 110^{o}C due to sealing problems limit compression ratios and may necessitate multi-stage units to maintain reasonable temperatures. The condensing pressure of the vapour stream which provides reboil heat to the same or adjacent system is limited by the reboiler temperature, and the various constraints on the compressor tend to limit the applicability of mechanical heat pumps.

Chemical heat pumps use simple surface exchangers with absorption fluid pumped in a closed circuit by single stage pumps. Close temperature approaches are used to remain within the maximum temperature lifts available with the absorption fluids, resulting in large exchangers.

A cost comparison between mechanical and chemical heat pumping is complicated by the relative scale of heat recovery with compressors requiring large vapour streams to be economic, while chemical systems have been relatively small.

A comparison of the two types of heat pumps has been made using the installed cost of a mechanical heat pump recently installed on a Butane Splitter at Dome Petroleum in Sarnia. Where relative duty and escalation is taken into account, the cost of the mechanical system is found to be 3 times high than the chemical heat pump used in this study. This is to be expected considering the complexity of the installation and the requirement for import duty imposed on the compressor, the latter accounting for the majority of the equipment costs.

A payout of 5 years is obtained for the mechanical heat pump.

Details of this comparison are provided in Appendix H.

3.11 Technology Transfer Benefits

For applications in the processing industry, chemical heat pumps have the distinct advantage over mechanical heat pumps of being capable of being completely built in Canada, with resultant benefits to Canadian Industry.

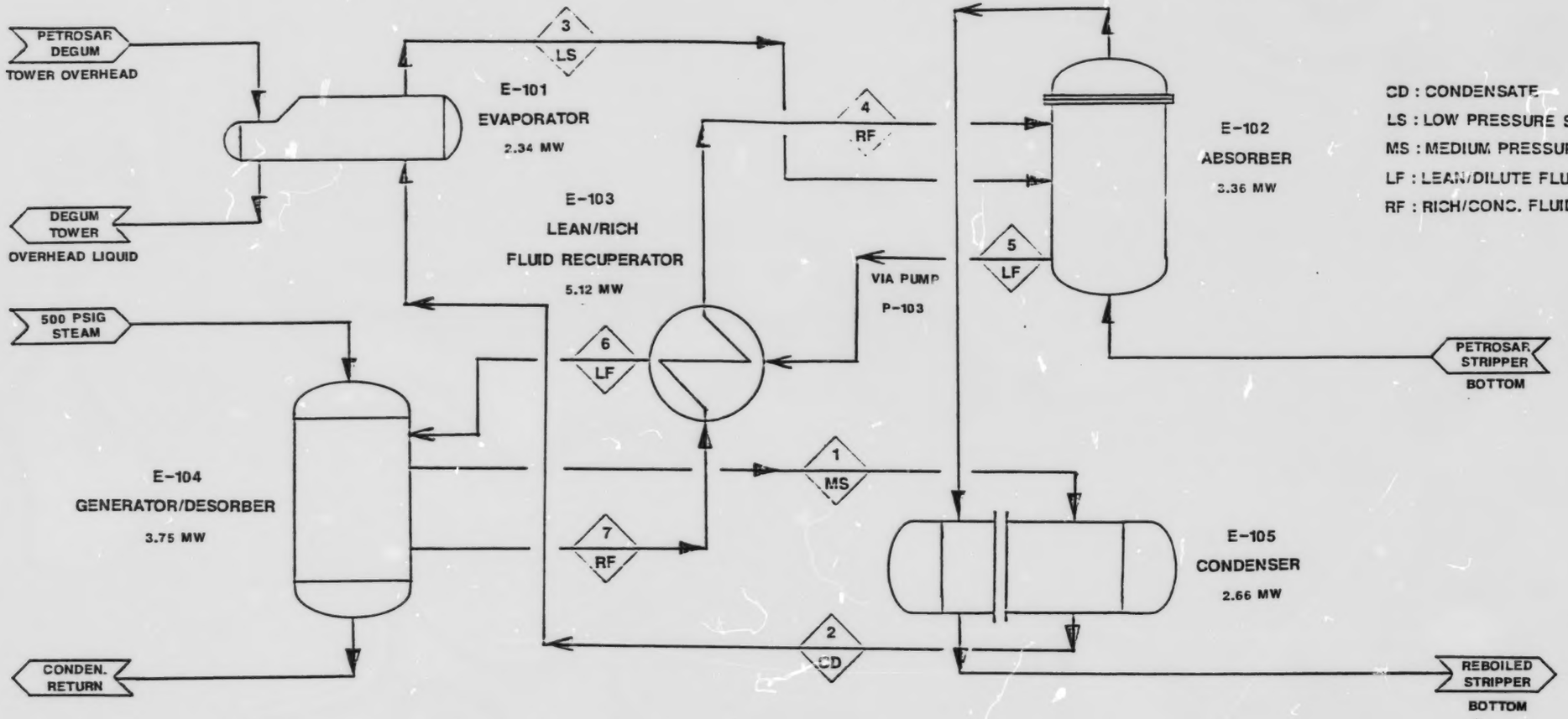
The centrifugal compressor used in the mechanical heat pump is not manufactured in Canada, although assembly and testing is often performed here. Thus nearly 75% of the major equipment costs of this type of installation are spent outside Canada, which represents approximately 25% of the installed cost.

Sectors of the Canadian economy that would benefit from the installation of chemical heat pumps include metal tube and plate manufacturers and their designers, together with the steel industry. These sectors of the industry have been particularly hard hit as a result of the fall in world crude

prices, and badly need an increased market. An estimated $89 MM in contracts, mainly in the steel fabrication sector, could result from amenable applications.

Details of this estimate are provided in Appendix I.

3.12 Process Flow Diagram and Material Balance (Figure 5)



Stream No.	Stream Description	Temp. (°C)	Pres. kPa(a)	Conc. (wt%)	Enthalpy (KJ/KG)	Flow (T/hr)
1-MS	Steam from generator	239	676.5	0	2954.02	4.25
2-CD	Condenser out	163	676.5	0	683.84	4.25
3-LS	Steam from evaporator	97	91	0	2670.29	4.25
4-RF	Solution to absorber	159	91	81.0	531.95	143.33
5-LF	Solution from absorber	148	90	78.7	511.48	147.87
6-LF	Solution to generator	234	676.5	78.7	552.89	147.87
7-RF	Solution from generator	239	676.5	81.0	660.81	143.33

PROCESS FLOW DIAGRAM AND MATERIAL BALANCE

CHEMICAL HEAT PUMP STUDY

DSS FILE : 04SQ.23440-5-9237

DELTA PROJECTS INC : 67250

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4.0 CONCLUSION

A new tertiary nitrate absorption fluid has been used in the design of a High Temperature Chemical Heat Pump application at Polysar (Corunna).

The new tertiary nitrate absorption fluid permits higher temperatures than previously possible with lithium-bromide, with a 260°C limit on the former versus 165°C for the latter.

Where Polysar (Corunna) steam costs and conditions are used, a payout in excess of 15 years is obtained. This poor payout results from a combination of an extremely low 1379 kPa(g) steam cost of $0.485/1000 kg obtained from turbine extraction, and the requirement for high priced alloy tubes in the process heat exchangers due to nature of the process at polysar.

A similar payback results where the cost of alloy tubes is replaced with carbon steel.

Where typical industry steam costs of $12.10/1000 kg are used, a payout of 4 years is obtained. While this payout does not meet the screening requirement of 2 years usually set for energy conservation applications, a steam cost of $18.74/1000 kg resulting from higher crude oil prices will make the High Temperature Chemical Heat Pump an economical method of heat recovery in the petrochemical industry.

A more favourable payout will result where the heat pump is integrated with the unit during the initial design phase, as credit can then be taken for elimination of equipment such as overhead condensers and reboilers whose duty is provided by the heat pump.

Comparisons between the two common types of heat pump indicates that the installed cost of the mechanical heat pump is 3 times higher than that for

the chemical heat pump when compared on the same basis for one typical installation in the petrochemical industry.

The High Temperature Chemical Heat Pump can be an economic option for energy conservation applications at steam costs of $18.74/1000 kg, and provides higher temperature lifts and will work at higher temperatures than previously available with lithium-bromide.

APPENDIX - A

Vendor Screening/Discussion
with the Heat Pump Vendors

EXHIBIT A - Kawasaki, Sanyo, Mycom, Ireq, Trane, Borg-Warner Air Products, Battle Mem. Inst., Brooklyn Gas Co., Litwin Engineers, Energy Concepts.

EXHIBIT B - Polysar

EXHIBIT C - Hitachi Zosen

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1. ABSTRACT

An international survey of the heat pump industry was conducted by Stearns Catalytic in order to identify vendors with experience in the design and manufacture of chemical absorption heat pumps. Litwin Engineers and Constructors Inc. and Energy Concepts Company were found to be the only North American companies offering chemical heat pump technology. Litwin claims a maximum design temperature of 400°F for a conventional lithium bromide heat pump utilizing Cu-Ni materials of construction. Energy Concepts will only guarantee their lithium bromide design up to 330°F, but they are experimenting with a new nitrate solution that appears to be compatible with carbon steel at temperatures up to 500°F. In Japan, Hitachi-Zosen Corporation and Tokyo Sanyo Electric Co. are the major chemical heat pump manufacturers, (no direct contact to date with Hitachi-Zosen), although both Hitachi Ltd. and Kawasaki Heavy Industries Ltd. have initiated chemical heat pump development programs. Discussions were also held with Petrosar, the host company, in order to choose an appropriate chemical heat pump application. Petrosar's Degum Tower was selected as a suitable candidate.

2. INTRODUCTION

In a continuing effort to promote the application of chemical heat pumps in Canadian industry, the National Research Council has authorized Stearns Catalytic to conduct a second more comprehensive Chemical Heat Pump Study. The main impetus will be to expand on information gathered in the previous study in order to improve the economics sufficiently to justify the construction of a demonstration chemical heat pump.

The scope of Task 1 of the study has been limited to the following areas:

- survey of the heat pump industry to identify vendors that have expertise in the design and manufacture of chemical absorption heat pumps.
- working with Petrosar, the host company, to select a suitable chemical heat pump application.

In this report, the results of these investigations are discussed.

3. DISCUSSION OF RESULTS

3.1 Discussions with Heat Pump Vendors

A survey of the heat pump industry in Canada, the United States, and Japan was made to identify companies with chemical absorption heat pump design and/or manufacturing experience. A total of seventeen companies were contacted; to date, thirteen responses have been received. The following list outlines the chemical heat pump capabilities of the companies approached:

Japan

- Hitachi Limited - manufacture water chillers, but not in a position to provide chemical heat pump quotations at this time.
- Kawasaki Heavy Industries Limited - not in a position to quote at this time, as their chemical heat pump system is still under development.
- Tokyo Sanyo Electric Company - design and manufacture chemical heat pumps, but limited by a maximum design temperature of 300°F.
- Hitachi-Zosen Corporation - no response.
- Mayekawa Manufacturing Company - no response.
- Ebara Corporation - no response.
- Hisaka Works Limited - no response.

Canada

- Mycom Canada Limited - specialists in vapour recompression, no experience with chemical heat pumps
- Institut De Recherche D'Hydro Quebec - Dr. P.M. Critchlow is a specialist in vapour recompression but has no in-depth knowledge of chemical heat pump.
- Trane Canada Limited - manufacture absorption water chillers, but have not diversified into chemical heat pumps.

United States

- Carrier Corporation - conducted a chemical heat pump market survey and concluded that there was insufficient demand.
- The Trane Company - no experience with chemical heat pumps

3. DISCUSSION OF RESULTS

3.1 Discussions with Heat Pump Vendors (continued)

United States (continued)

- York International Limited (formerly Borg-Warner) - no longer in the chemical heat pump business
- Air Products Limited - no experience with chemical heat pumps
- Battelle Memorial Institute - their chemical heat pump technology was sold to Adolph Coors Co., who subsequently sold it to Litwin Engineers and Constructors Inc.
- Brooklyn Gas Company - currently the North American distributor for Hitachi water chiller units; hope to distribute chemical heat pumps for Hitachi in approximately two years time.
- Litwin Engineers & Constructors Inc. - offer conceptual and detailed design of chemical heat pumps, including project management and commissioning services.
- Energy Concepts Company - only provide conceptual process design of chemical heat pumps at a cost of $150 per computer run. As North American agents and distributors of Hitachi-Zosen equipment, they can supply an Hitachi-Zosen chemical heat pump package complete with technical and troubleshooting backup. No project management or commissioning services provided.

For additional information concerning the above companies see Exhibit 'A'.

The results of the survey showed that there are only two companies in North America that are seriously involved in the design of chemical heat pumps: Litwin Engineers and Constructors Inc. and Energy Concepts Company. Litwin has clearly stated a willingness to provide a detailed chemical heat pump design to be built by Canadian manufacturers. In the case of Energy Concepts, owing to their affiliation with Hitachi-Zosen, their preference is to supply an Hitachi-Zosen package unit. Although to date, no response has been received from Hitachi-Zosen, W. Davidson of Energy Concepts claims that Hitachi-Zosen and Sanyo are the major chemical heat pump manufacturers in Japan. Efforts are continuing to contact Hitachi-Zosen directly.

3. DISCUSSION OF RESULTS

3.1 Discussions with Heat Pump Vendors (continued)

It appears that both Hitachi and Kawasaki have chemical heat pump development programs in progress, and may be entering the market in the near future.

Further discussions with Litwin and Energy Concepts revealed a number of differences in their respective designs:

(a) Maximum Lithium Bromide Solution Temperature - Litwin claims a maximum allowable solution temperature of 400°F using Cu-Ni construction and a special inhibitor package. Energy Concepts follows Hitachi-Zosen's more conservative approach, specifying a maximum solution temperature of 330°F using Cu-Ni material and conventional corrosion control methods developed in the absorption refrigeration industry. Energy Concepts are of the opinion that accepting solution temperatures above 330°F, translates into higher corrosion rates and a subsequent shortening of equipment life.

(b) Economic Temperature Lift Attainable

Litwin - 70% of the difference between the waste heat and heat sink temperatures

Energy Concepts - difference between the waste heat and heat sink temperatures minus 50F°

(c) Chemical Heat Pump Solution

Litwin - Lithium Bromide/Water

Energy Concepts - In addition to the customary lithium bromide/water solution, Energy Concepts have patented a new nitrate/water fluid. Laboratory tests have demonstrated its compatibility with carbon steel at temperatures up to 500°F. They will be releasing a report on this fluid at the end of April/86. An effort will be made to keep abreast of any new developments including pilot plant trials scheduled for this summer.

3.2 Discussion with Petrosar

Stearns Catalytic met with Petrosar on April 1, 1986, (See Exhibit 'B') at which time three potential chemical heat pump applications were considered:

1) Stripper Tower
   - currently using 200 psig saturated steam at $2.20/1000 lbs.
   - reboiler duty is 80.5MM BTU/Hr.

2) Degum Tower
   - reboiled with 500 psig steam at $3.08/1000 lbs., pressure reduced and desuperheated to 400°F maximum
   - reboiler duty is 15 MMBTU/Hr.

3. DISCUSSION OF RESULTS

3.2 Discussion with Petrosar (continued)

3) Production of 100 psig dilution steam at $2.20/1000 lbs. from 70°C quench water, using a two stage chemical heat pump.

The third option was quickly eliminated because it was found that even a two-stage chemical heat pump generated insufficient temperature lift to produce 100 psig dilution steam. In selecting a suitable distillation tower for chemical heat pump application, two methods of heat recovery must be considered. The waste heat obtained from the tower overheads stream can either be recycled back into the bottom of the tower via the heat pump's absorber unit, or used to produce medium pressure steam. Energy Concepts holds a patent on the recycle of heat to the tower, thereby limiting Litwin's design to the production of steam. The Stripper Tower appeared to be a suitable applicant for a chemical heat pump based on the preliminary process data supplied by Petrosar; unfortunately, further study revealed a large condensing temperature range on the overheads vapour stream. This made it impossible to generate sufficient temperature lift to recycle waste heat back to the tower, or to produce steam at a practical pressure. The Degum Tower was found to be a suitable candidate and will consequently form the basis of this study.

The Degum Tower bottoms temperature is above Energy Concept's design limit of 330°F; therefore, they propose to recycle the waste heat from the Degum Tower overheads back to the bottom of the Stripper Tower. Litwin would simply produce 100 psig dilution steam from this waste heat. A Sanyo design will also be considered; however, their temperature ceiling of 300°F may prove too restrictive.

4. CONCLUSIONS AND RECOMMENDATIONS

1) Litwin Engineers and Constructors Inc. and Energy Concepts Co. are the only companies in North America offering chemical heat pump technology.

2) Litwin Engineers and Constructors Inc. are more receptive than Energy Concepts Co. to the idea of maximizing Canadian manufacturing content.

3) Hitachi-Zosen Corporation and Tokyo Sanyo Electric Co. appear to be the major Japanese manufacturers of chemical heat pumps, but no direct response has yet been elicited from Hitachi-Zosen.

4) Hitachi Ltd. and Kawasaki Heavy Industries Ltd. are currently engaged in chemical heat pump development programs and may soon enter the market.

5) The maximum operating temperature for chemical heat pumps using a lithium bromide solution and Ni-Cu construction is 400°F. However, a special inhibitor package is required above 330°F.

6) It is recommended that the new nitrate soTution developed by Energy Concepts Co. be considered as a future alternative to lithium bromide. Lower equipment costs would significantly improve chemical heat pump economics.

7) Petrosar's Degum Tower has been selected as a suitable candidate for the Chemical Heat Pump Study.

EXHIBIT 'A'

STEARNSCAT SAR

T•

STEARNSCAT SAR

HITACHY J22395

ZCZC

FROM HITACHY TOKYC

GK
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/99922
=216476130•STEARNSCAT SAR

86/04/09 18:39

TC 064-76130 STEARNSCAT SAR (CANADA)
FM HITACHY TOKYC

4/09/HCN046
XEL/R 2504
ATTN: MR.L.J.SPAULDING,
MGR OF PROCUREMENT,
SUE : CANADIAN GOVERNMENT - DEPARTMENT
OF SUPPLY AND SERVICES
REF : YR TLX SCL PROJECT 2493

THANK YOU VERY MUCH FOR YOUR INQUIRY. BUT WE REGRET THAT WE ARE NOT IN A POSITION TO QUOTE THE ABSORPTION HEAT PUMP UNITS FOR CHEMICAL PROCESS APPLICATION.

BEST REGARDS,
S.SUZUKI/XEL DEPT., HITACHI LTD., TOKYO

FILE NAME-N0918273

TTLX NO.106182[illegible]

STEARNSCAT SAR
T•
STEARNSCAT SAR

242437IKAWAJU J
TC FM TCK 1120-3213 04.10 20:06

CC Dave Heath

TO: MR LJ SPAULDING

STEARNS CATALYTIC LTD

FM: KEN MIYAKOSHI
SR MGR, OVERSEAS MARKETING DEPT
KAWASAKI HEAVY INDUSTRIES , LTD TOKYO

DATE: APRIL 9, 1986

RE: SCL PROJECT 2493

THANK YOU FOR YR TLX OF APRIL 7, INQUIRING
FOR OUR AHP TECHNOLOGY.

WE REGRET NOT BEING IN A POSITION TO QUOTE
FOR ANY SPECIFIC PROJECT AT THIS MOMENT,

SINCE OUR AHP IS STILL UNDER PROCESS OF R&DD.

- OUR MAJOR INTERESTS IN ADVANCED HEAT PUMP
- ARE CHEMICAL ABSORPTION, METAL HYDRIDES AND
- SO FORTH, UTILIZING HIGHER TEMPERATURE WASTE HEAT.
-

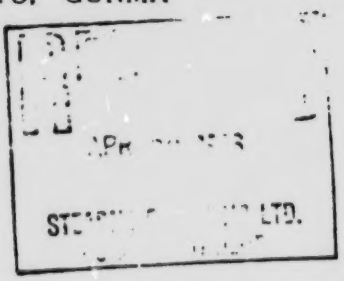
FOR YR INITIAL INQUIRY TO OUR FIRM, PLS FEEL
FREE TO CONTACT ME AND I HOPE WE COULD BE
OF SERVICE TO YOU SOON.

THANKS AND REGARDS.

SANYO TOKYO SANYO ELECTRIC CO., LTD.

OIZUMI. GUNMA 370-05, JAPAN
PHONE: 0276-63-2111
TELEX: 3473385, T SANYO J
CABLE ADDRESS: TOKYOSANYO, GUNMA

Dave Isell



Mr. L. J. SPAULDING
Manager of Procurement
Stearns Catalytic Ltd.
265 North Front Street
Sarnia Ontario Canada

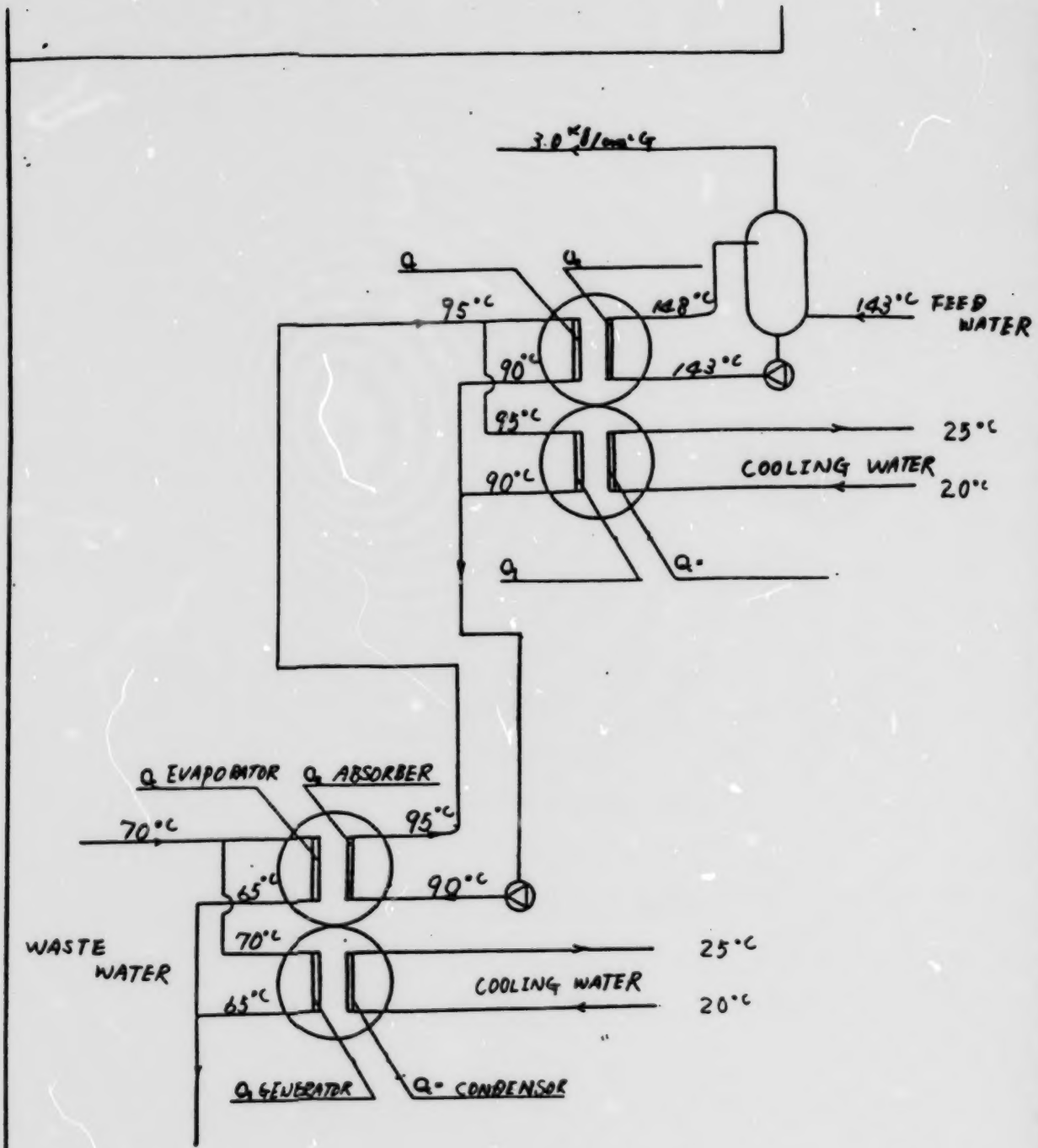
April 18, 1986

Dear Mr. Spaulding

Thank you very much for your telex of April 7 and April 16, 1986.
In connection with your No. 1 question, the maximum process temperature is 150 Degree C.
And regarding the idea of using two stage AHP, please refer to the drawing enclosed.
If you are interested in the informations sent by us, will you please send detailed data.

Sincerely yours,

T. MINAMI
Manager
Air-Conditioning Division



	尺度	承認	検図
	日付	設計	作図

東京三洋電機株式会社

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Ken Akaike
COMPANY Stearns Catalytic	COMPANY Mycom Ltd., B. C.

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Informed by K. Akaike that Mycom deals only with vapour recompression units and not absorption heat pumps.

DISTRIBUTION: P. Cullen
P. Davies
File
~~D. Heath~~

STEARNS CATALYTIC

FORM 62.20
REV. 5-75

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Dr. P. M. Critchlow
COMPANY Stearns Catalytic	COMPANY IREQ (Hydro Quebec)

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Informed that Dr. P. M. Critchlow is a specialist in vapour recompression, but has no in-depth knowledge of absorption heat pumps.

DISTRIBUTION: P. Cullen
P. Davies
File
D. Heath

STEARNS CATALYTIC

FORM 62.20

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Colin Pergins
COMPANY Stearns Catalytic	COMPANY Trane Co., Toronto

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Colin Pergins thinks that Trane's absorption cold generator might be adapted for use as an absorption heat pump. He is forwarding literature on this unit.

DISTRIBUTION: P. Cullen
P. Davies
~~D. Heath~~
File

STEARNS CATALYTIC

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Engineering Department
COMPANY Stearns Catalytic	COMPANY Carrier Corporation, N. Y.

SUBJECT: Contract 2493
ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Carrier investigated the use of absorption heat pumps in the U. S. chemical/ petrochemical industries, and concluded that the market was too small for them to pursue.

DISTRIBUTION: P. Cullen
P. Davies
File
D. ~~Heath~~

STEARNS CATALYTIC

FORM 62.20

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Greg Natvig
COMPANY Stearns Catalytic	COMPANY Trane Co., Wisconsin

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

G. Natvig has no knowledge of Trane being involved in the application of absorption heat pumps for distillation energy conservation. He suggested that I speak to Colin Pergins in their Toronto office.

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P. Davies
File
~~D. Heath~~

STEARNS CATALYTIC

FORM 62.20

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-07

FROM:	TO:
NAME David Heath	NAME John Ferguson
COMPANY Stearns Catalytic	COMPANY York International, PA. (formerly Borg-Warner)

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Informed by J. Ferguson that York International is no longer in the absorption heat pump business. Referred to Carrier, Trane and Brooklyn Gas as possible suppliers.

DISTRIBUTION: P. Cullen
P. Davies
File
~~D. Heath~~

STEARNS CATALYTIC

FORM 82.20

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Tom Cormier
COMPANY Stearns Catalytic	COMPANY Air Products

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

Informed by T. Cormier that Air Products has no capabilities with regard to absorption heat pump design. Referred to D. Erickson of Energy Concepts.

DISTRIBUTION: P. Cullen
P. Davies
~~D. Heath~~
File

STEARNS CATALYTIC

FORM 62.20

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME David Ball
COMPANY Stearns Catalytic	COMPANY Battelle Memorial Institute

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

D. Ball indicated that the Battelle Memorial Institute sold its absorption heat pump technology to Adolph Coors Co., who subsequently sold it to Litwin Engineers and Contractors Inc. When questioned about lithium bromide solution/Ni-Cu alloy compatibility, he said that above 330°F, corrosion is serious enough to require a special inhibitor package.

DISTRIBUTION: P. Cullen
P. Davies
~~D. Heath~~
File

STEARNS CATALYTIC

FORM 62.20
REV. 5-75

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-07

FROM:	TO:
NAME David Heath	NAME John Sasso
COMPANY Stearns Catalytic	COMPANY Brooklyn Gas Co., N. Y.

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

J. Sasso indicated that Brooklyn Gas is currently the North American distributor for Hitachi Chiller units. They also hope to distribute absorption heat pumps for Hitachi in the future; however, J. Sasso feels that it will be at least two years before this happens. Referred to Matt Nagao at Hitachi's New York manufacturing plant.

DISTRIBUTION: P. Cullen
P. Davies
File
~~D. Heath~~

STEARNS CATALYTIC

FORM 61-20

RECORD OF TELEPHONE CONVERSATION

DATE 86-04-07

FROM:	TO:
NAME David Heath	NAME Malcolm Pettigrew
COMPANY Stearns Catalytic	COMPANY Litwin Engineers & Constructors Inc.

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS (AHP)

TOPICS OF CONVERSATION:

Informed by M. Pettigrew that Litwin offers the following services:

- conceptual process design of AHP's.
- detailed AHP design.
- project management and commissioning.

- Litwin prefers to provide a detailed rather than conceptual AHP design because they consider the exchanger internals to be an integral part of the design.

- Litwin recommends a maximum allowable AHP temperature of 400^{o}F with Cu-Ni alloy, resulting in a maximum column bottoms temperature of approximately 380^{o}F.

- Litwin has tested SS/lithium bromide solution compatibility at temperatures above 400^{o}F, only to find that stress corrosion cracking is a serious problem.

- M. Pettigrew's initial response to the use of a two stage AHP to produce medium pressure steam from quench water was that two stage units are generally uneconomical; however, he is willing to investigate our specific case further.

Litwin recommends adherence to the following guidelines in order to obtain an economical AHP design:

- minimum waste heat temperature of 180^{o}F.
- two year payback period.

DISTRIBUTION: P. Cullen
P. Davies
D. Heath
File

STEARNS CATALYTIC

FORM 62.20

RECORD OF TELEPHONE CONVERSATION

DATE 86-04-07

FROM:	TO:
NAME	NAME
COMPANY	COMPANY

SUBJECT:

TOPICS OF CONVERSATION:

- maximum temperature lift per stage is 70% of the difference in waste heat and heat sink temperature.

DISTRIBUTION;

STEARNS CATALYTIC

FORM 62-20
REV. 5-75

RECORD OF TELEPHONE CONVERSATION

DATE 86-04-08

FROM:	TO:
NAME David Heath	NAME Bill Davidson
COMPANY Stearns Catalytic	COMPANY Energy Concepts Co.

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS (AHP)

TOPICS OF CONVERSATION:

Bill Davidson outlined the following services provided by Energy Concepts Co. (ECC):

- preliminary AHP process design at a cost of $150/computer run.
- detailed AHP design by Hitachi-Zosen.
- technical and troubleshooting backup from Hitachi-Zosen.
- no project management or commissioning services provided.

- Bill Davidson indicated that Hitachi-Zosen takes a very conservative position with respect to temperature limitations of the Cu-Ni alloy used; corrosion is considered prohibitive above 330°F, resulting in a maximum allowable column bottoms temperature of approximately 310°F.
- ECC feels that claimants of a higher Ni-Cu alloy temperature limit are simply accepting much higher corrosion levels.
- ECC has recently patented a new AHP fluid:

  absorbent - ternary nitrate (mixture of nitrates)

  refrigerant - water
- New fluid is chemically stable up to 850°F and lab tests have shown it to be compatible with CS at temperatures up to 500°F.
- ECC to release a report on this ternary nitrate fluid at the end of April, followed by construction of a pilot plant this summer.
- Bill Davidson stated that at present there are no AHP systems operating in North America.

DISTRIBUTION: P. Cullen
P. Davies
~~D. Heath~~
File

STEARNS CATALYTIC

RECORD OF TELEPHONE CONVERSATION

DATE 86-04-08

FROM:	TO:
NAME	NAME
COMPANY	COMPANY

SUBJECT:

TOPICS OF CONVERSATION:

- ECC mentioned the possibility of using more than one waste heat source to improve the economics an AHP applied to distillation, e.g. steam requirements are reduced by running an AHP on not only the column's own condenser waste heat but also that of another distillation column.
- When queried about the possibility of producing medium pressure steam from 70°C quench water with a two stage AHP, Bill Davidson's response was that generally two stage AHP's are uneconomical, i.e. additional energy savings does not justify the increased capital expenditure.

DISTRIBUTION:

STEARNS CATALYTIC

FORM 62.20
REV. 5.75

RECORD OF TELEPHONE CONVERSATION

SHEET 1 OF 1

DATE 86-04-11

FROM:	TO:
NAME David Heath	NAME Bill Davidson
COMPANY Stearns Catalytic	COMPANY Energy Concepts Co. (ECC)

SUBJECT: Contract 2493

ABSORPTION HEAT PUMPS

TOPICS OF CONVERSATION:

ECC conducted a preliminary analysis of a two stage absorption heat pump to produce medium pressure steam from 70°C quench water. Using a conservative temperature lift per stage, ECC feels that only 20 psig steam can be produced economically.

DISTRIBUTION: P. Cullen
P. Davies
~~D. Heath~~
File

STEARNS CATALYTIC

EXHIBIT 'B'

C LM 109

INTER-OFFICE MEMO

STEARNS CATALYTIC

TO: See Distribution AT

FROM: P. Cullen AT

SUBJECT: Contract 2493
Supply & Services Canada
Chemical Heat Pump Study - Phase 2
MINUTES OF MEETING - APRIL 1, 1986

DATE: April 10, 1986

COPY TO: Attendees
M. Wiggan (EMR)
K. Snelson (NRC)
~~2494-208~~

Meeting No. 1

A meeting was held at Polysar on April 1, 1986 to select the application to be used for the above project.

PRESENT:	POLYSAR	STEARNS CATALYTIC
	D. Hutchins	P. Davies
	E. Debevc	D. Heath
	G. Gilbert	P. Cullen

1. Background

Polysar had previously suggested the use of the Stripper Tower (DA-4002) in the above study, but current crude oil prices result in low costs for the 200# steam used in this tower. Other applications were thus reviewed as follows in an attempt to locate a more profitable application.

2. Degum Tower

This tower uses 500# steam desuperheated to 400°F maximum and carries a steam cost of $ /1000 lbs. versus $ /1000 lbs. for 200# steam.

Reboiler duty is 15 MM BTU/hr.

Tower conditions provided to Stearns Catalytic.

This application exceeds the 330°F maximum temperature listed by some vendors and will be reviewed.

3. Dilution Steam

Polysar have a large requirement for dilution steam (100# at 170°C) quench water at 70°C was identified as a potential heat source.

Temperature lift required for this application exceeds the single stage capability of a heat pump and thus a 2-stage application will be reviewed.

4. Application Selection

Stearns Catalytic will review both the maximum temperature limitation and the feasibility of a 2-stage system with all vendors currently offering chemical heat pump technology, and based upon this select the application to be studied in detail.

P Cullen.

P.D. Cullen, P.Eng.
Project Manager

PDC/pm

EXHIBIT 'C'

Hitachi Zosen

ABSORPTION HEAT PUMP

The Hitachi Zosen Absorption Heat Pump recovers heat from large volumes of warm waste water or condensable vapor to generate high-temperature steam or to heat water. This absorption heat pump is a result of Japanese research and development, part of the Moonlight Project sponsored by the Agency of Industrial Science and Technology of MITI. For this project, Hitachi Zosen was entrusted to develop the "waste heat recovery high temperature heat pump," a waste heat utilization system.

This heat pump is a highly reliable equipment based on Hitach Zosen's experience as a plant builder and is the most suitable system for energy savings in various types of plants, and in many different ways.

HITACHI ZOSEN HEAT PUMP IS THE KEY TO EFFECTIVE

FEATURES:

The Hitachi Zosen absorption heat pump is an extremely safe and reliable piece of equipment which uses water as a working fluid and LiBr solution as an absorbent. The four heat exchangers consist of shell and tube type and are installed vertically. The system has the following capabilities:

1. Steam or Hot Water is Produced only from Waste Heat
Since the driving force of the absorption heat pump is heat, only a very small amount of electrical power is needed to drive circulation pumps.

2. Improved Heat Utilization
Because the heat exchanger is of the counter current type, the absorption heat pump can utilize lower temperature heat sources and produce higher temperatures at the outlet.

3. Suitable as a Steam Generating System
Water vaporization is possible within the heat transfer tube, providing steam 5—10°C hotter than that generated in the horizontal type of absorption heat pump.

4. Suitable for Heat Recovery from Waste Vapor
Since vapor is condensed to form the falling film, heat from the waste vapor can be recovered without hindrance to the operation of the plant.

5. Small Area Required for Installation
The four main heat exchangers are of the vertical type for outdoor installation and require only a small amount of space.

6. Available for Water Chilling
This heat pump is also available as an absorption chiller, using waste heat. Since it has four circulation pumps, it is available as an absorption chiller or an absorption heat pump with the same equipment.

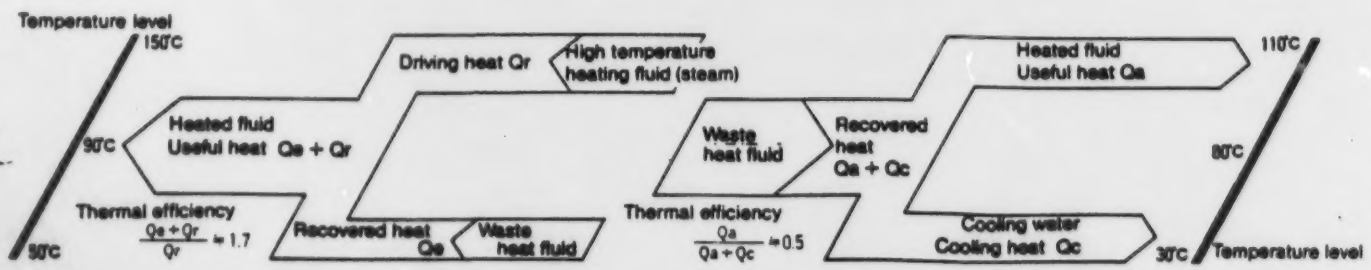
APPLICATIONS:

- Generation of steam for chemical processes by heat recovery from overhead distillation vapor.
- Water heating for district heating, air conditioning, agriculture and fisheries by recovery of plant waste heat or environmental heat.
- Preheating boiler feed water by recovery of plant waste heat.
- Other process heating (e.g. for purifying water) by recovery of waste heat.
- Reducing distillation energy requirement by 45 percent of the top gas waste heat.

TYPES:

The absorption heat pumps are principally classified into two types, referred to as Type I and Type II.

Type I Absorption Heat Pump



Type II Absorption Heat Pump

UTILIZATION OF ENERGY

PRINCIPLE OF OPERATION:

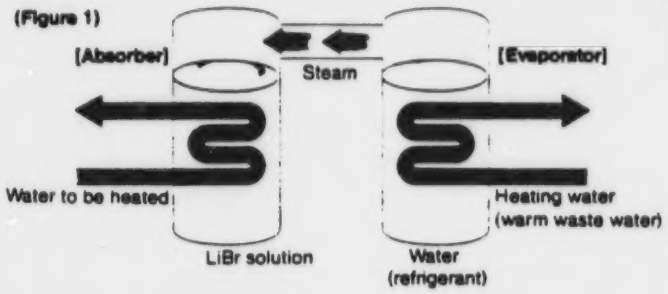
The boiling point of a LiBr solution is higher than that of water under the same pressure. The higher the concentration of the LiBr solution, the higher the boiling point. For example, under a pressure of 300 mmHg abs., the boiling point of water is 76°C, but that of a 60% LiBr solution is 128°C, approximately 50°C higher. The absorption heat pump utilizes this difference in boiling points. If the evaporator, containing water, and the absorber, containing 60% LiBr, are connected, the temperature of the absorbent must rise approximately 50°C higher than that of the water in the evaporator so that a pressure equilibrium is reached between the two media. Then, if the water in the evaporator is heated, steam is generated and the temperature and pressure in the evaporator rise slightly. The slight pressure difference causes the steam to move into the absorber where it is absorbed into the LiBr solution. As the steam is absorbed and gives off its latent heat of condensation, the temperature of the LiBr solution rises to a temperature which is once again about 50°C higher than that of the water, restoring the equilibrium. If the LiBr solution is cooled by a cooler fluid, the same process will take place continuously.

Through this process, the same heat that is used to evaporate the water is transferred to the incoming fluid in the absorber at about 50°C higher than the water temperature and the fluid is thereby heated. (Figure 1)

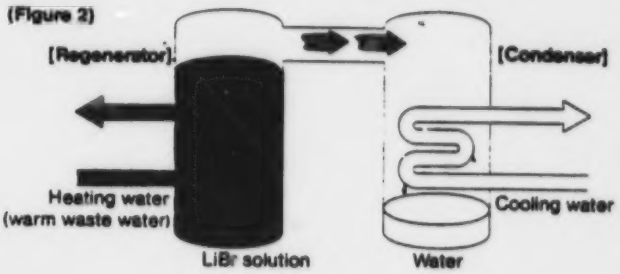
However, as the LiBr solution continues absorb the steam, it is diluted and the absorbing capability is weakened. Therefore the dilute LiBr solution must be regenerated. When the weak LiBr solution is sent to the regenerator and heated with warm water, water in the LiBr solution is desorbed as steam and the LiBr solution in the regenerator is concentrated. Steam flows back into the condenser and condenses into water. In this example, warm waste water should have a temperature of 50°C higher or more than the cooling water. (Figure 2)

The absorption heat pump continuously performs this process in which the LiBr solution absorbs and desorbs steam, and thereby converts the heat contained in the warm waste heat to steam at a higher temperature and another at a lower temperature. (Figure 3)

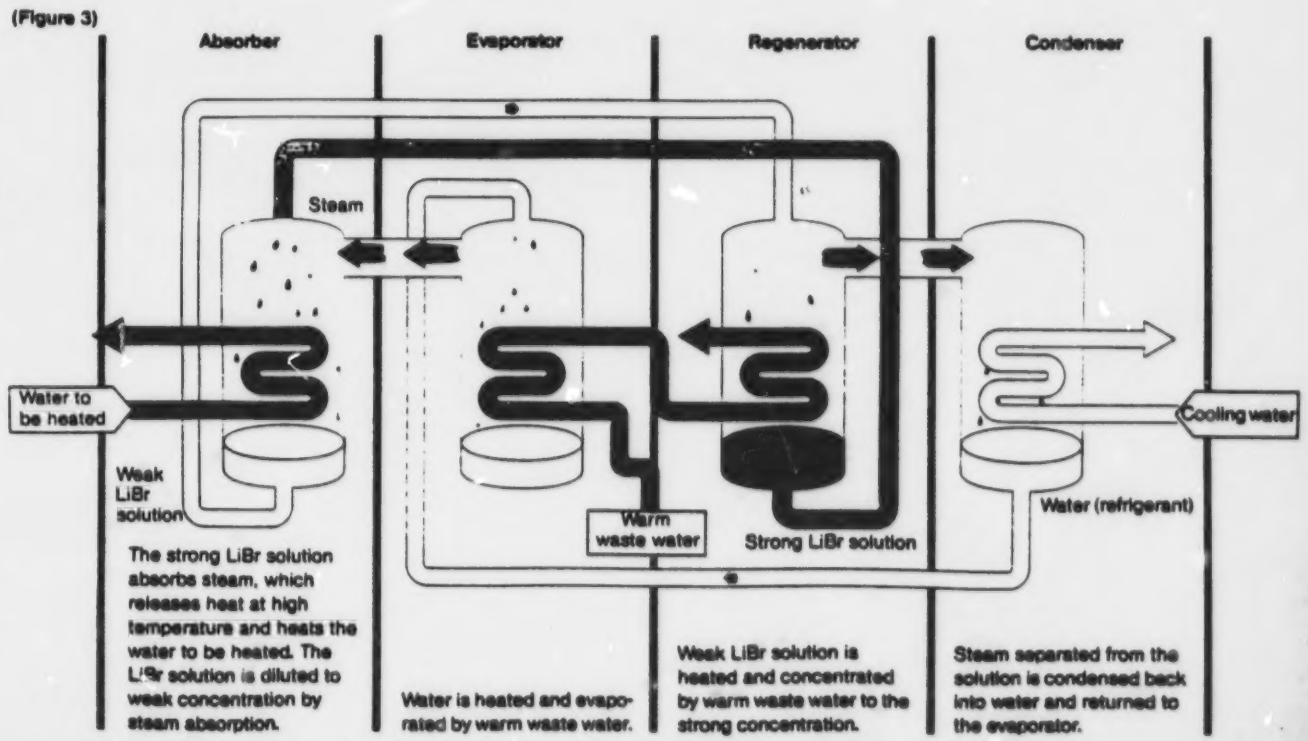
(Figure 1)



(Figure 2)

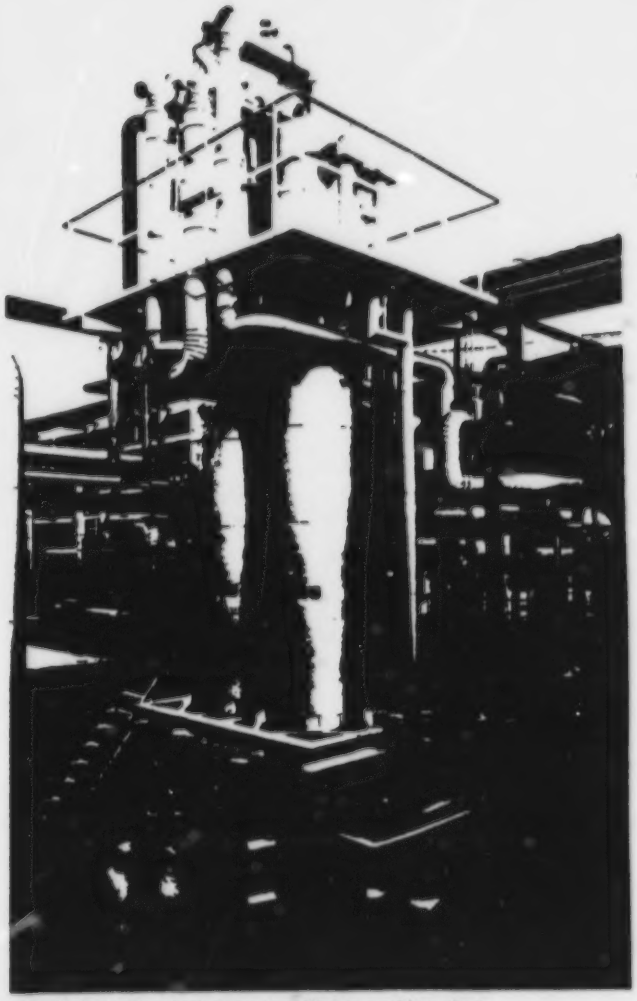


(Figure 3)


Absorber
Evaporator
Regenerator
Condenser
Steam
Water to be heated
Cooling water
Weak LiBr solution
Warm waste water
Strong LiBr solution
Water (refrigerant)
The strong LiBr solution absorbs steam, which releases heat at high temperature and heats the water to be heated. The LiBr solution is diluted to weak concentration by steam absorption.
Water is heated and evaporated by warm waste water.
Weak LiBr solution is heated and concentrated by warm waste water to the strong concentration.
Steam separated from the solution is condensed back into water and returned to the evaporator.

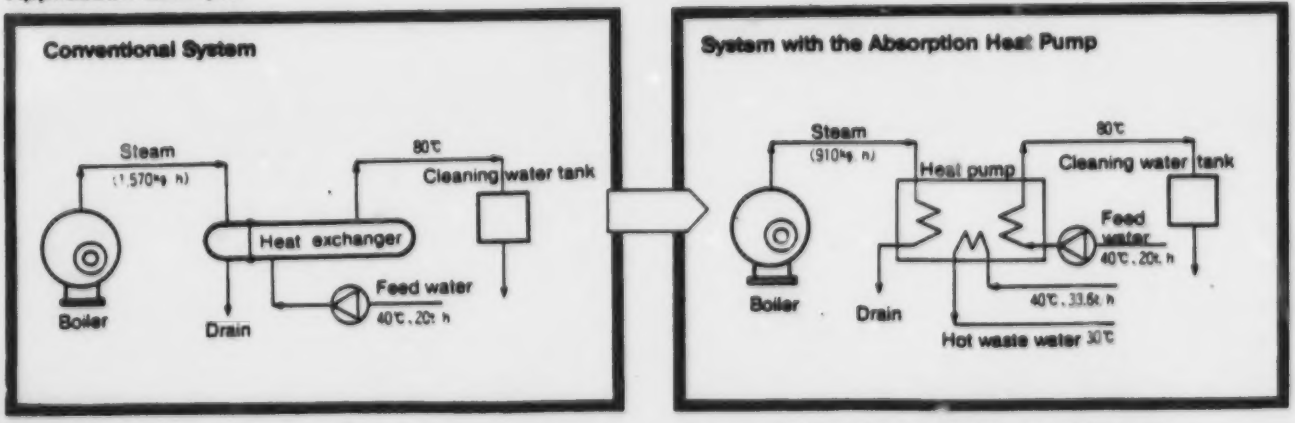
TYPE I ABSORPTION HEAT PUMP

The Type I absorption heat pump supplies useful heat both from the absorber and condenser.
The Type I absorption heat pump produces approximately 1.7 times the heat quantity of heat in the high temperature fluid (steam) supplied to the regenerator. The temperature of the useful heat output is between that of the high temperature fluid and the warm waste fluid.
This process needs approximately 40% less steam than normally required to heat water with steam only.
The Type I absorption heat pump is suitable for use where the temperature of warm waste fluid is between 10°C and 60°C.



Type I absorption heat pump installed in a rubber plant.

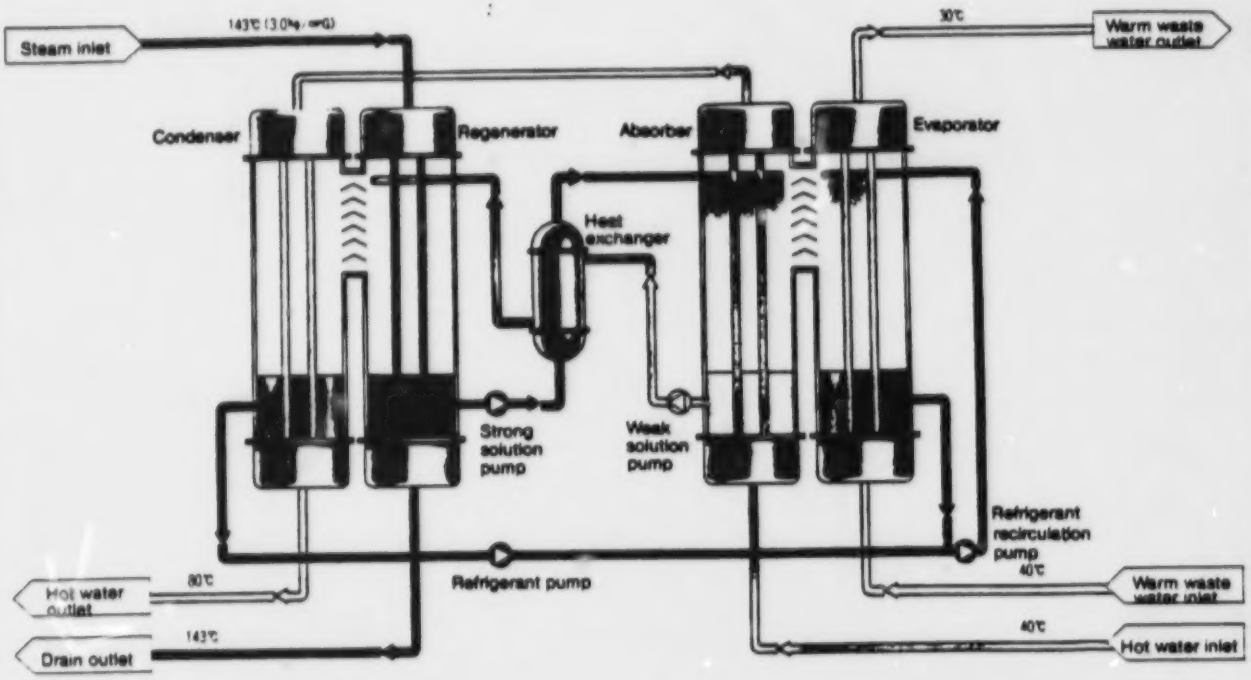
Application Example



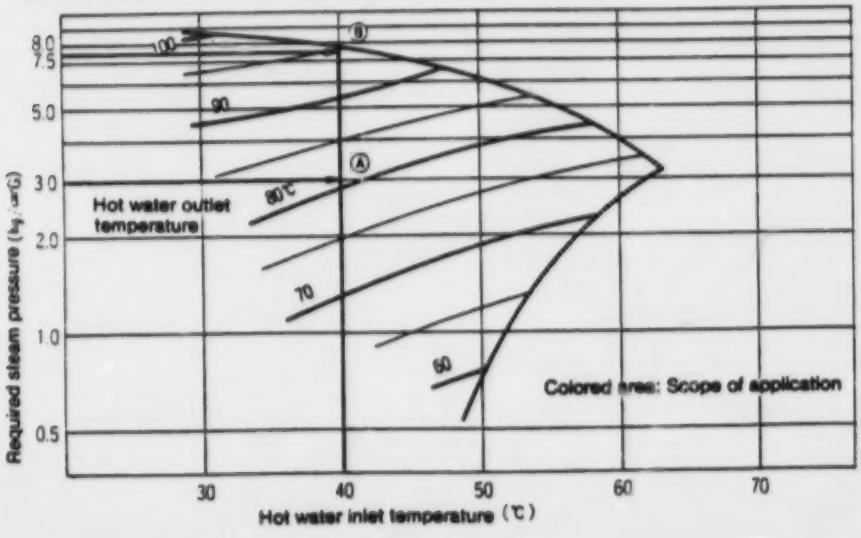
The required heat quantity of the hot water for cleaning is 800,000 kcal/h. In this case, fuel consumption is 96 kg/h if the boiler efficiency is 85% and the calorific value of the fuel is 9,800 kcal/kg.

If warm waste water at 40°C is available, the absorption heat pump reduces the boiler fuel consumption to 55.7 kg/h and an energy saving of more than 40% is realized.

Type I Absorption Heat Pump



Type I Absorption Heat Pump Performance Map



Waste Heat· Generated Heat

Water Vapor (cooled from 40°C to 30°C) → Hot water

1. Heat Balance

Useful heat output Qac = 2.5 Qe
Steam heat input Qr = 1.5 Qe

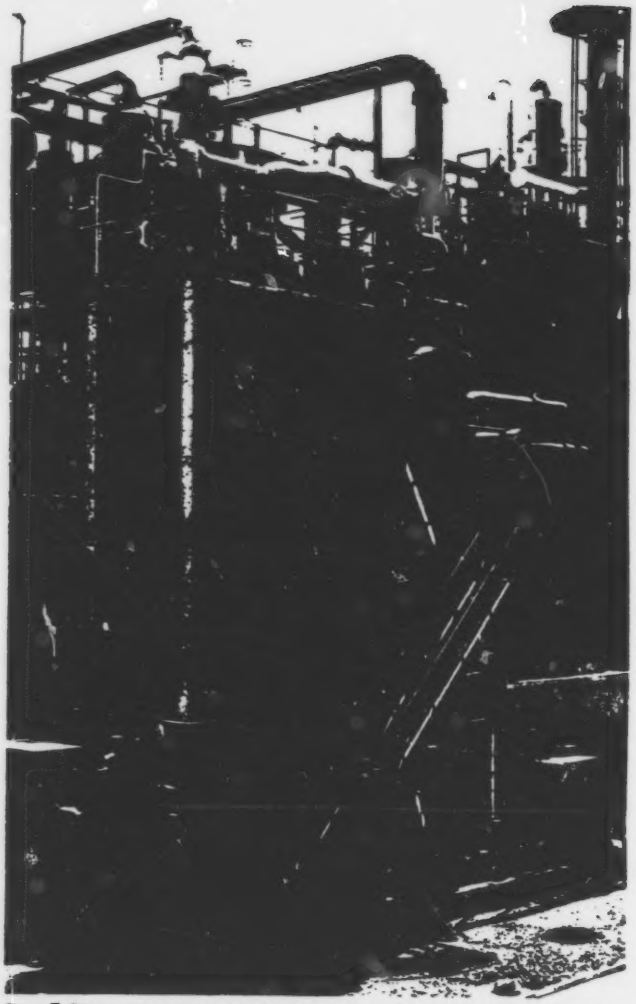
Qe: Incoming heat input to the evaporator (kcal/h)
Qr: Incoming heat input to the regenerator (kcal/h)
Qac: Useful heat output from the absorber and the condenser (kcal/h)

2. How to Read the Performance Map

If the steam pressure is 3.0 kg/cm²G and the hot water inlet temperature is 40°C, hot water (point A) of approximately 80°C is obtained. When the steam pressure is 7.5 kg/cm²G, hot water (point B) of approximately 95°C is obtained.

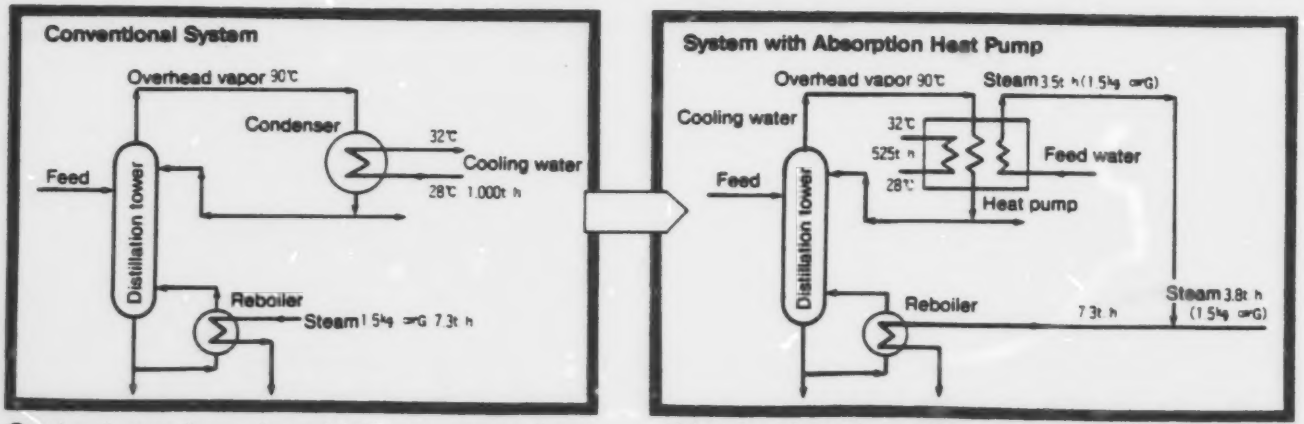
TYPE II ABSORPTION HEAT PUMP

The Type II absorption heat pump uses the waste heat as the driving force of the heat pump and delivers heated fluid or vaporized steam having a temperature higher than the temperature of the waste heat fluid, by as much as the difference between the waste heat fluid and the cooling water temperature.
The recovered upgraded heat is approximately 50% of the waste heat.
Therefore the Type II absorption heat pump is suitable for obtaining steam or high temperature hot water from waste heat fluid having a relatively high temperature.



Type II Steam generation absorption heat pump installed in a chemical plant.

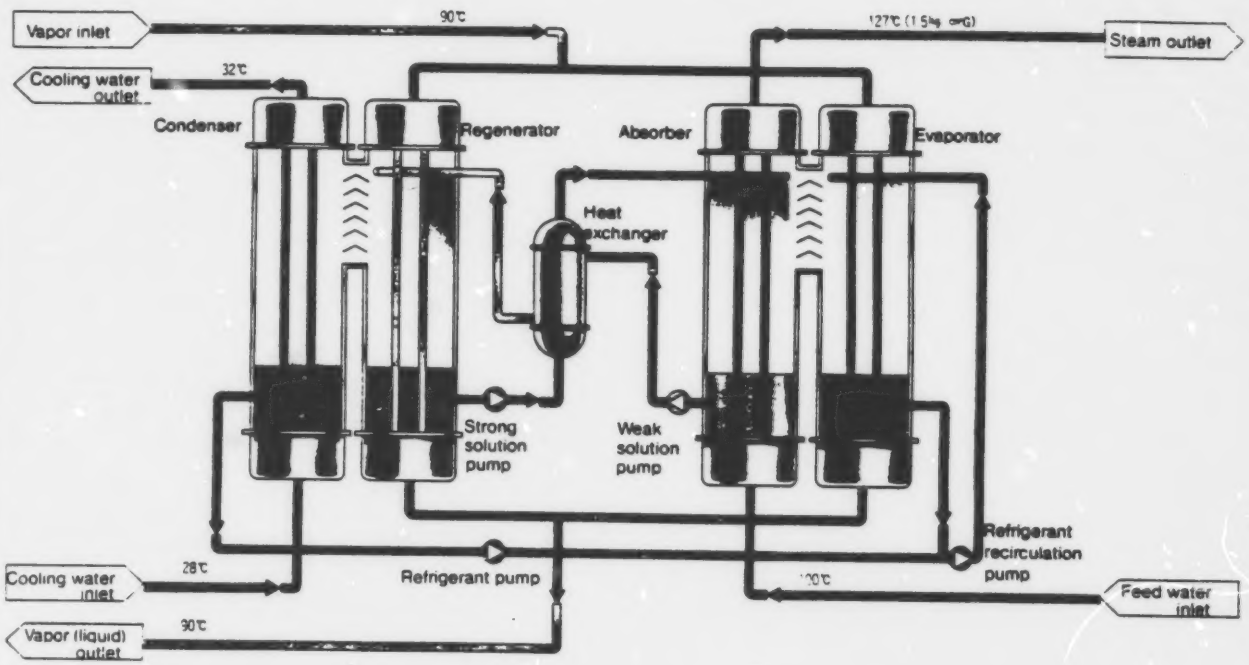
Application Example



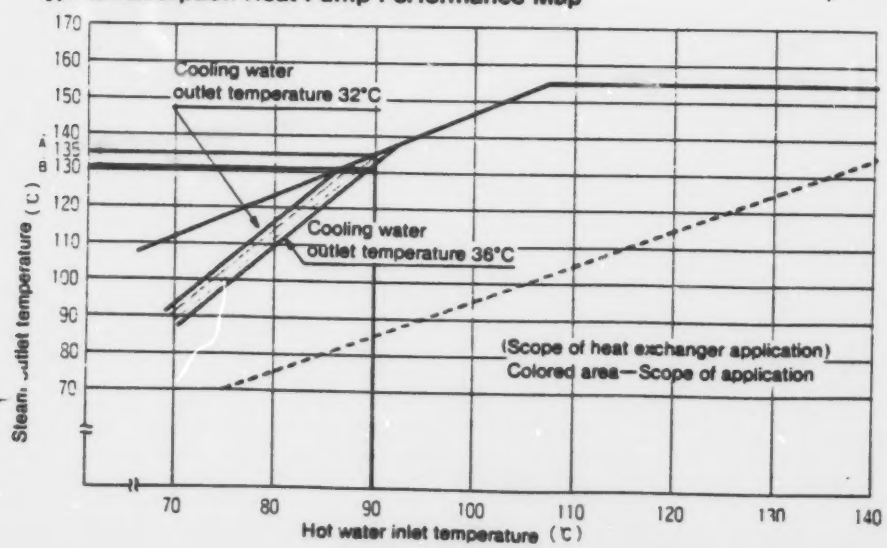
Overhead vapor is condensed in the condenser. (heat duty: 4,000,000 kcal/h)

When the absorption heat pump is applied to the example at the left, steam of approximately 1,900,000 kcal/h (3.5 t/h) can be produced for heating the reboiler by recovering waste heat from condensing overhead vapor. The net steam required to drive the distillation tower is thereby reduced from 7.3 t/h to 3.8 t/h.

Type II Absorption Heat Pump



Type II Absorption Heat Pump Performance Map



Waste Heat **Generated Heat**
Vapor → Steam

1. Heat Balance

Generated useful heat

$Qa = 0.48\ Qer$

Heat rejected to cooling water

$Qc = 0.52\ Qer$

Qer: Waste heat supplied (kcal/h) to the evaporator and the regenerator
Qa: Heat output (kcal/h) from the absorber
Qc: Heat output (kcal/h) from the condenser

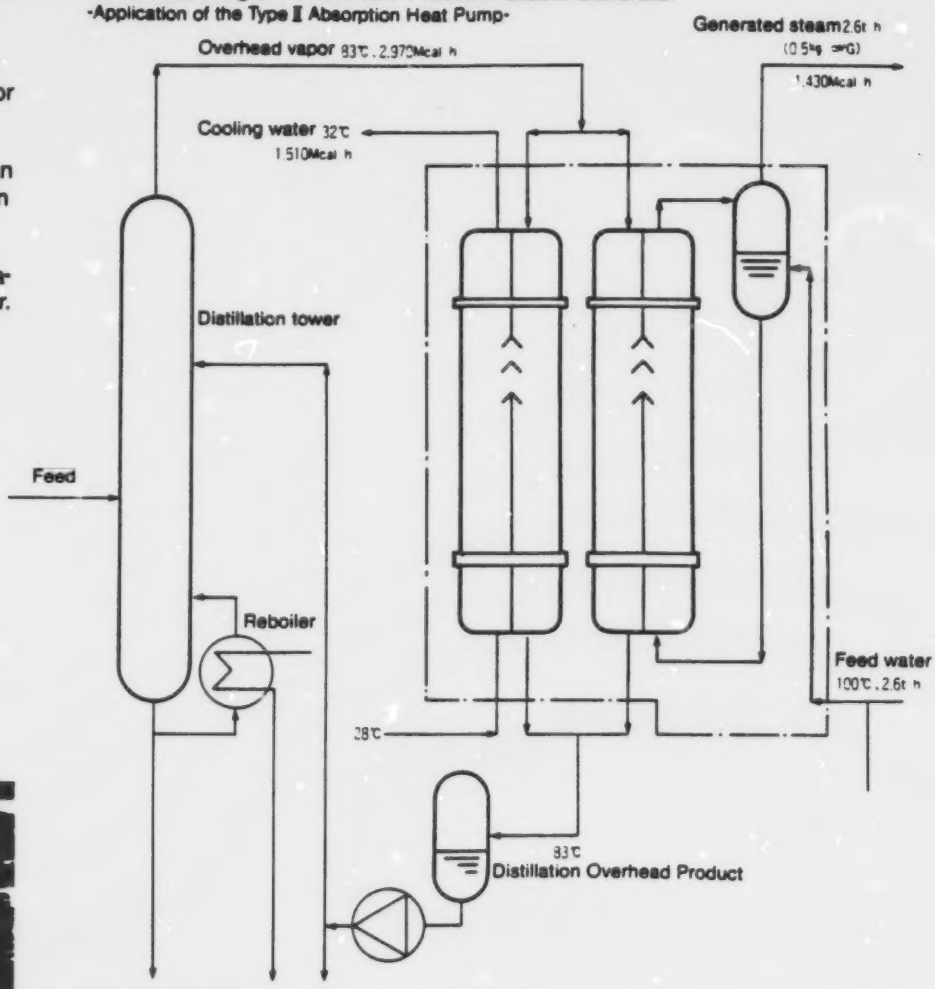
2. How to Read the Performance Map

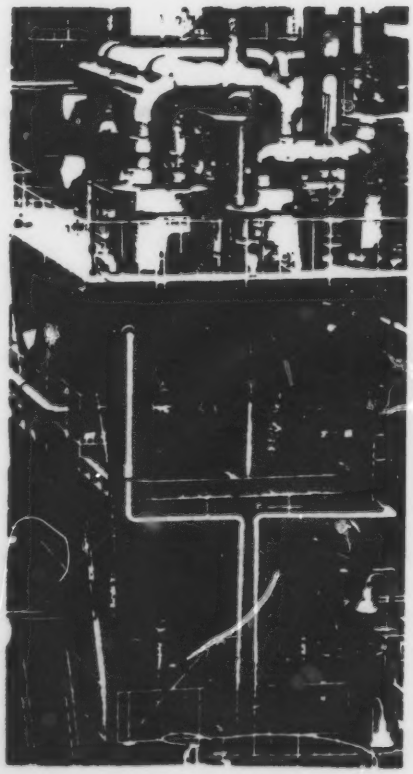
If the cooling water outlet temperature is 32°C and the vapor inlet temperature is 90°C, steam of up to 135°C (2.2 kg/cm²G, point A) is obtained. When the cooling water outlet temperature is 36°C, steam of up to 130°C (1.7 kg/cm²G, point B) is obtained.

EXAMPLE OF ACTUAL INSTALLATION

In this example, the system recovers heat from waste vapor of 83°C to generate low-pressure steam of 0.5 kg/cm²G (111°C), which can be used to reboil the bottom product or used elsewhere in the plant. This example illustrates the savings in energy consumption achieved by an absorption heat pump applied to an existing distillation tower; the low-pressure steam is generated by recovering latent heat of condensation from the tower overhead vapor.

Schematic Diagram of the Low Pressure Steam Generator
-Application of the Type II Absorption Heat Pump-





Economic Evaluation under Japanese conditions

The following shows the economic advantages of the absorption heat pump when used as a waste heat recovering unit.

Conditions:
- Unit price of steam $12.0/ton
- Unit price of power $0.06/kW
- Annual operation time 8,000 h/year

Annual profit A by steam saving

A = (Amount of saved steam) × (Unit price of steam) × (Annual operation time)

= 2.6 t/h × $12.0/t × 8,000 h/year = $249,600/year

Annual power cost B for the absorption heat pump (except for utilities)

B = (Power consumption of absorption heat pump) × (Unit price of power) × (Annual operation time)

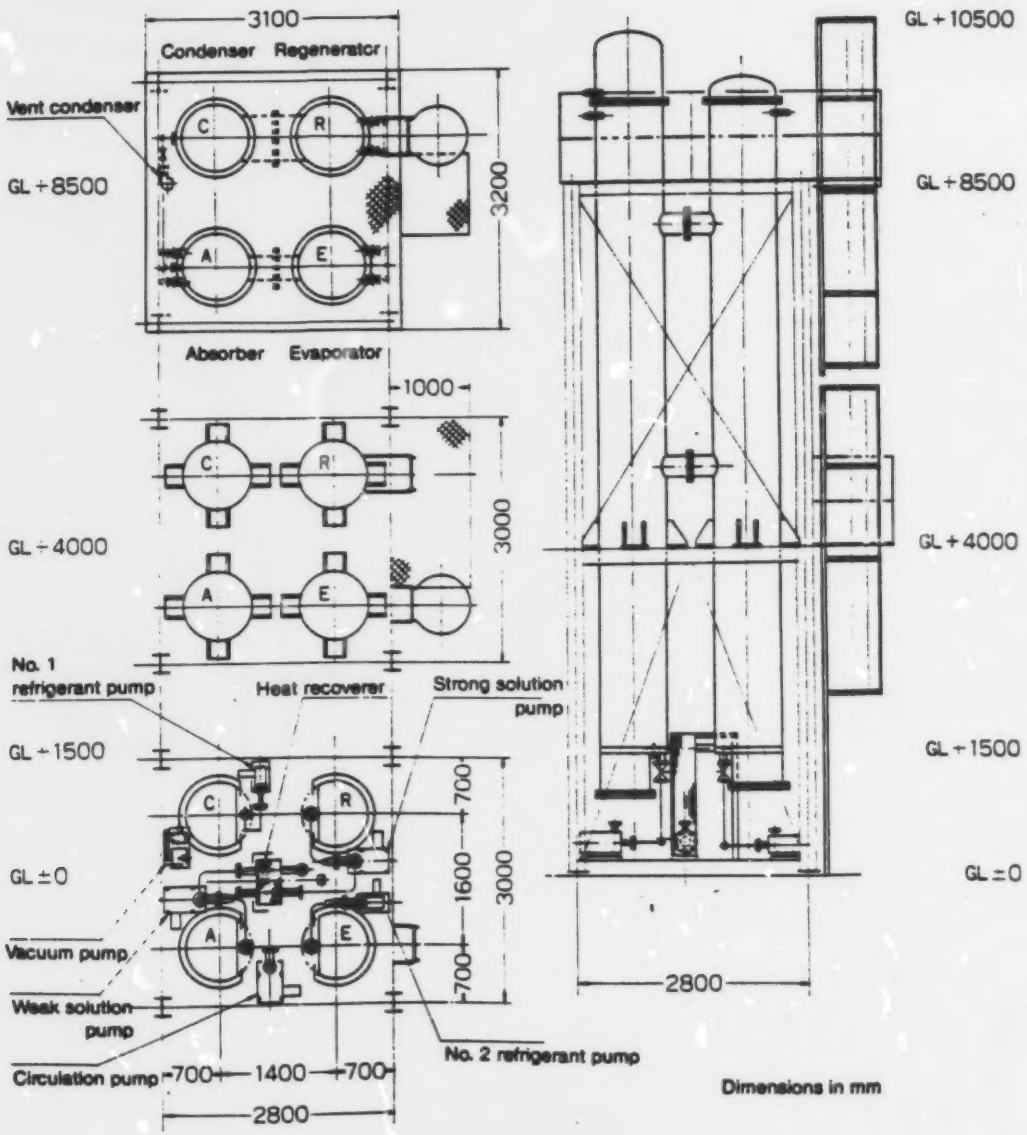
= 23.6 kW/h × $0.06/kW × 8,000 h/year = $11,328/year

Net annual profit C by the absorption heat pump

C = $249,600/year — $11,328/year

= $238,272/year

STANDARD PLOT PLAN OF HITACHI ZOSEN ABSORPTION HEAT PUMP



Dimensions in mm

HHP-2S-75 (packaged type)

Hitachi Zosen

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Telex: 887171 USA UD

Printed in Japan No. L-832B December 1984/Ms-D.P.

APPENDIX - B

HEAT PUMP INITIAL INQUIRY

1. SCOPE

a. The work shall consist of furnishing and delivering to the jobsite at Sarnia, Ontario, Canada one (1) Chemical Absorption Heat Pump Unit, complete with accessories as specified herein.

b. Unloading, installation and field testing will be performed by others; however, the Seller shall provide the services of a qualified representative for start-up supervision to ensure the safe and successful operation of his equipment.

c. Following award of Contract and approval of drawings, Seller will be required to furnish three (3) copies of certified drawings, final process flowsheets, specifications, operating instructions, and installation manuals for the entire Chemical Absorption Heat Pump Unit. These items must be submitted to Purchaser prior to delivery of equipment to jobsite.

2. EQUIPMENT TO BE FURNISHED

The equipment to be furnished shall consist of an evaporator, condenser, generator, absorber, cross-exchanger, necessary pumps and connecting piping, i.e., all equipment that is an integral part of the Chemical Absorption Heat Pump Unit.

3. OPERATING CONDITIONS

A. Environmental

The Chemical Absorption Heat Pump Unit will be installed outdoors and shall incorporate all features necessary for satisfactory operation under the following environmental conditions:

a. Plant elevation above mean sea level: 605 feet (184.4 m).

b. Barometric pressure: 14.4 psia (29.3 inches mercury).

c. Ambient temperature ranges:

Summer -	Dry Bulb	92°F
	Wet Bulb	76°F
Winter -	Dry Bulb	-6°F

B. Conditions of Service

1. Cooling water is available at the plant site at the following conditions:

a)	Design Temperature:	27°C
b)	Maximum Pressure:	60 PSIG
	Design Pressure:	90 PSIG

3. OPERATING CONDITIONS

B. Conditions of Service (continued)

2. Steam is available at the plant site at the following conditions:

a) 200 PSIG Saturated, Design Pressure = 250 PSIG

b) 500 PSIG Saturated, Design Pressure = 600 PSIG

3. Instrument air is available at the plant site at the following conditions:

a) Pressure: 80 PSIG

b) Dryness: -40°F Dewpoint

4. DESIGN AND CONSTRUCTION

A. General

a. The equipment to be furnished under this Specification shall be a standard packaged unit of the manufacturer. Where two (2) or more units of the same class of equipment are required, the units shall be products of the same manufacturer; however, the component parts need not be the products of the same manufacturer.

b. The equipment furnished shall be of materials compatible with the fluids and gases with which the units will come into contact.

c. Components, features and design parameters specified herein are minimum requirements. If Seller's design dictates that these minimum requirements shall be exceeded to meet specified performance guarantees and to provide safe reliable operating units, it shall be Seller's responsibility to furnish all equipment above and beyond the specified minimum requirements at no increase to his original bid price.

d. All electric motors furnished as part of the equipment shall have a permanent nameplate which shall include horsepower rating, etc.

e. The Chemical Absorption Heat Pump shall be mounted on one or more skids for installation by others.

f. Instrumentation necessary to monitor operation of the system shall be included and installed where appropriate.

g. All pumps, valves, and miscellaneous equipment, necessary to provide a complete Chemical Absorption Heat Pump system shall be included.

4. DESIGN AND CONSTRUCTION

A. General (continued)

h. All pressure vessels shall be fabricated, where applicable, in accordance with Section VIII of the ASME Code and the requirements of the Province of Ontario Ministry of Consumer and Corporate Relations (MCCR). Where applicable, all vessels and exchangers shall be registered with the MCCR, the cost of same being to the vendor's account.

i. All heat exchangers shall be fabricated in accordance with T.E.M.A. standards, Class 'R'.

j. All electrical components shall meet the requirements of the Canadian Standard Association, Canadian Electrical Manufacturer's Association, and Ontario Hydro. In addition, all instrumentation shall meet the requirements of the Instrument Society of America.

k. All skid mounted piping and equipment shall be hydrotested and completely drained and dried prior to shipment. Connecting piping outside skid battery limits to be supplied by others.

l. The vendor's price shall include for witnessing of shop tests by representatives of Stearns Catalytic and/or the owner.

m. All power and instrument wiring within the confines of each skid, including suitable junction boxes at the limit of each skid, shall be provided by the Chemical Absorption Heat Pump Vendor.

n. All instrumentation supplied for the unit shall be in the following units:

Temperature	-	Celsius
Pressure	-	PSI
Flow	-	USGPM

o. The equipment shall be operated in a Class 1 Division II Group C & D electrical area.

p. All piping and equipment flanges shall be in accordance with ANSI requirements.

q. The Chemical Absorption Heat Pump system shall be designed for completely automatic operation, with annunciation provided for major operation faults.

r. Power Supply Voltages - 575V 3 Phase 60 Cycle
208V 3 Phase 60 Cycle
120V 1 Phase 60 Cycle

5. FINISHING AND PAINTING

Finishing and painting shall be Manufacturer's Standard.

6. NOISE EMISSION

A. The Seller is obligated to comply with the laws of the Province of Ontario and the Federal Government as to permissible noise exposure to personnel within the plant area and maximum permissible noise levels at the site boundaries. Accordingly, certain noise emission data is requested of the Seller in the Bid Data Section for each piece of equipment, excluding electric motors, furnished by the Seller. Control of excessive noise emissions will be an evaluation consideration.

B. The maximum permissible equivalent A-rated sound level is 85 dBA, based on a free field measured from a distance of 5 feet and in accordance with AMCA Standard 300, and AMCA Publication 303.

7. SPECIAL TOOLS AND DEVICES

One (1) complete set of all special tools or devices required for operation and/or maintenance of the equipment furnished under this Specification shall be provided and delivered with the equipment in a separate container clearly marked with the name of the equipment.

8. SHOP ASSEMBLY AND TEST

A. Equipment furnished under this Specification shall be shop assembled and shipped ready for installation.

B. Equipment shall be tested in the Seller's shop as necessary to prove satisfactory operation for the service specified.

C. Decision by the Buyer not to witness the shop tests or to conduct shop inspection shall in no way relieve the Seller from full responsibility for the quality and correctness of the work.

D. No part of the above paragraphs shall in any way void, restrict or limit the right of the Buyer to later conduct such performance tests as it may desire or its rights under any warranty or guarantee.

9. FIELD TESTS

Following final installation of the equipment, the Buyer will conduct standard tests to determine that the equipment meets specified operational requirements. Should these tests indicate that the equipment does not meet the specified requirements, the costs of all corrective measures shall be borne by the Seller until such time as tests demonstrate that the specified requirements have been met. Field tests will be made at the Buyer's expense except that the Seller shall furnish a qualified representative to

9. FIELD TESTS (continued)

supervise and witness such tests and remain at the site until tests have been completed and approved by the Buyer. The Seller will be given two weeks advance notice of the pending tests to allow scheduling of required personnel.

10. PREPARATION FOR SHIPMENT

A. Disassembly and Crating

For shipment, the equipment shall be skidded, crated or otherwise suitably protected against damage or loss during shipment and to facilitate field handling. All openings shall be closed with temporary closures to prevent entry of dust, dirt, moisture or other foreign matter.

B. Tagging Instructions

a. All crates, boxes, bags or items shipped loose or skidded shall contain the following information:

(1) Buyer's Purchase Order Number
(2) Buyer's Purchase Order Item or Tag Number
(3) Equipment Serial Number

b. Items not crated or boxed shall be tagged with metal tags securely attached and containing the information set forth above.

c. Seller shall require sub-suppliers to follow these tagging instructions.

11. GUARANTEES

A. The Seller shall guarantee that the equipment furnished conforms to the requirements set forth and to the specified Codes, Standards and Regulations, and that all specified tests have been satisfactorily completed.

B. The foregoing shall not be construed in any way to limit or negate any other standard guarantees or portion thereof which may provide a more comprehensive guarantee than those required by this Specification.

EQUIPMENT DATA SHEET

Stearns Catalytic

☐ STUDY ☐ PROPOSAL ☒ INQUIRY ☐ PROJECT

		TAG NO	PAGE 1 OF 4
		PROJECT NUMBER 2494	
CLIENT & LOCATION: Petrosar, Sarnia, Ont.	PROJECT: CHEMICAL HEAT PUMP	DATE May 2, 1986	BY D.Heath
		INSPECTION CODE	
MANUFACTURER	SERVICE DEGUM TOWER	SELLER	

USING MIXED NITRATES AS THE ABSORBENT

Vendor to propose a Chemical Absorption Heat Pump System as follows:

Stearns Catalytic prefers quotation for:

1. Technology supply only, including license fee, approximate equipment sizes, and budget installation price.

If this is not possible then provide quotation based on:

2. Technology, license fee, major equipment, and budget installation price in accordance with the attached "Detailed Specification".

DESIGN CRITERIA

a) Degum Tower condenser duty, Q = 16.0 MM BTU/HR.

b) Cooling water design temperature is 27°C.

Allowable cooling water temperature rise is 16.7°C (27-43.7°C).

c) Degum Tower is in C_9^+ aromatics service.

d) Stripper Tower bottoms contains benzene, toulene, xylene, water and heavies.

e) Stripper Tower Reboiler inlet temperature - 134°C.

f) Stripper Tower Reboiler outlet temperature - 159°C.

g) Distance between the Degum and Stripper Towers is approximately 300 feet.

h) For Degum Tower overheads cooling curve see Fig. (i).

J) Degum Tower design pressure is 30 PSIG.

I) FOR STRIPPER REBOILER HEAT CURVE SEE FIG. 2

REVISIONS Date & By	0	ORIGINAL ISSUE 5/15/86							

EQUIPMENT DATA SHEET

STEARNS CATALYTIC

☐ STUDY ☐ PROPOSAL ☒ INQUIRY ☐ PROJECT

TAG NO	PAGE 2 OF 4
PROJECT NUMBER 2494	
DATE MAY 2, 1986	BY D. HEATH
INSPECTION CODE	

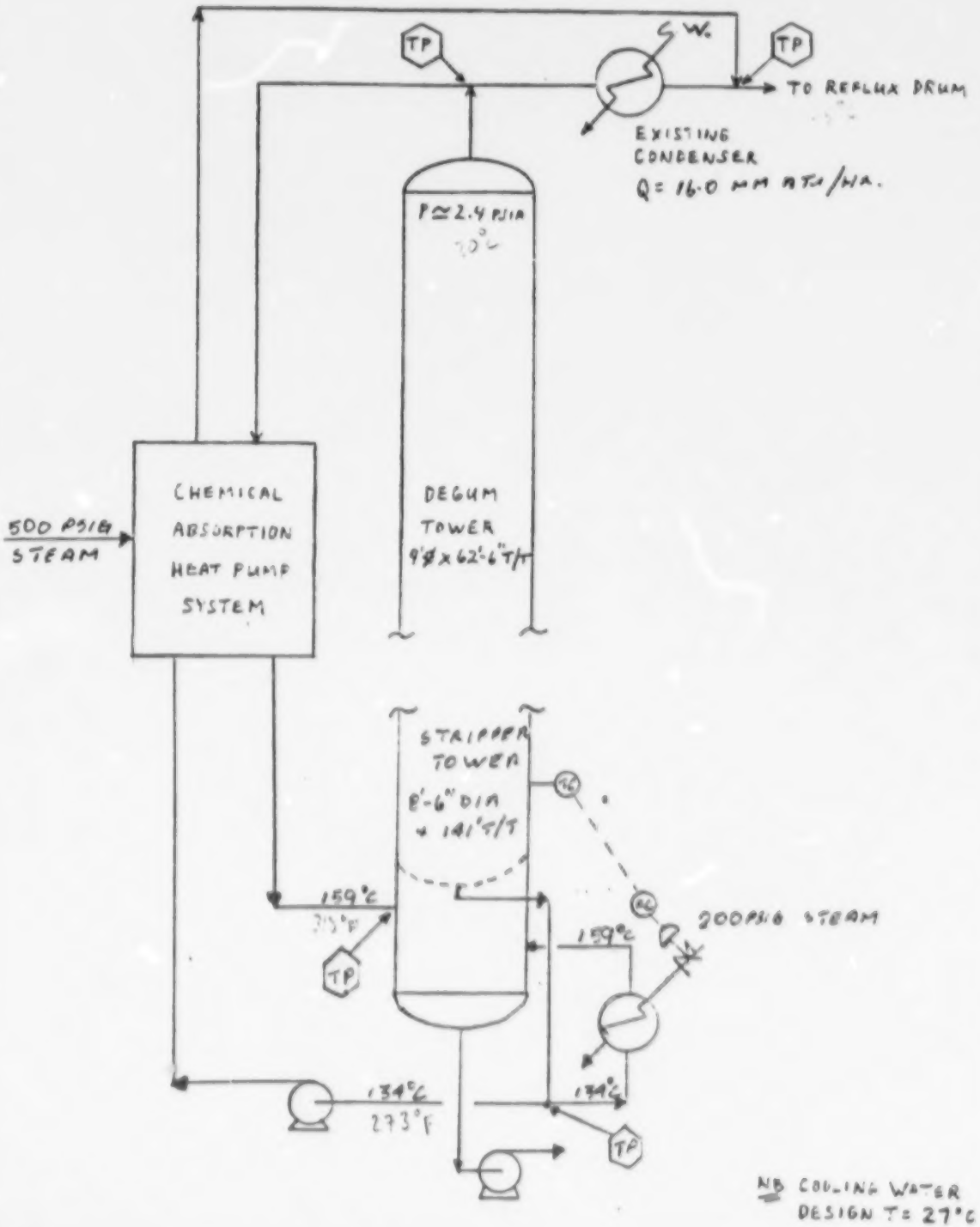
CLIENT & LOCATION: PETROSAR, SARNIA, ONTARIO

PROJECT: CHEMICAL HEAT PUMP

MANUFACTURER

SERVICE: DEGUM TOWER

SELLER

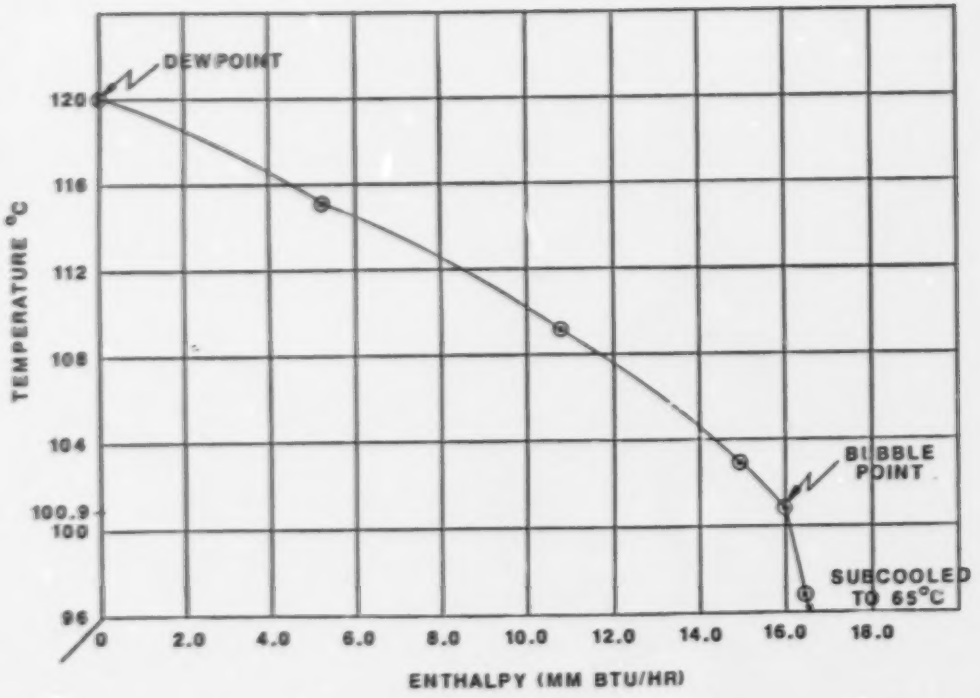


NB COOLING WATER
DESIGN T = 27°C

REVISIONS (Date & By)								
0	ORIGINAL ISSUE							

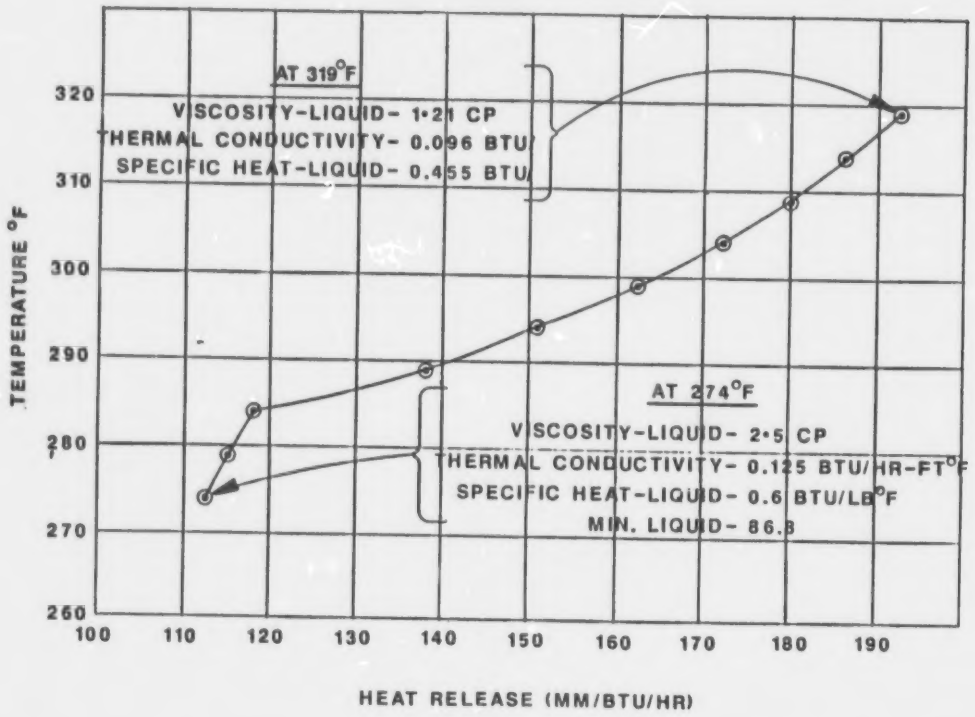
DEGUM TOWER
OVERHEADS COOLING CURVE

FIGURE 1



STRIPPER REBOILER (EA-4003)
HEAT CURVE (87.5% TETRAETHYLENE GLYCOL)

FIGURE 2



APPENDIX - C

HIGH TEMPERATURE ABSORPTION FLUID

APPENDIX -C

500°F ABSORPTION HEAT PUMP UNDER DEVELOPMENT

W. F. Davidson and D. C. Erickson
Energy Concepts Company
Annapolis, Maryland

ABSTRACT

Economical industrial heat pumping to temperatures above 500°F (260°C) is promised in the near future. A new absorption fluid is the key. Tested under DOE sponsorship, the new fluid has proven to be thermally stable and noncorrosive to austenitic stainless steel up to 500°F, or mild steel up to 430°F. Heat transfer properties are comparable to those of the conventional LiBr-H_2O system. Paired with water as the working fluid, laboratory tests have shown that useful temperature lifts of over 162°F (90°C) ΔT can be achieved allowing 10°F heat exchangers. The fluid is nontoxic and noncombustible. Good economics for the system should stem from (1) high temperature capabilities for wider and more highly valued uses, (2) high internal temperature lifts for low heat exchanger surface areas, (3) predominantly carbon steel components, and (4) better COP in the heat amplifier mode than current absorption heat pumps. Recent laboratory results are presented including temperature applicability maps.

FIGURE 1

HEAT AMPLIFIER APPLICABILITY DIAGRAM

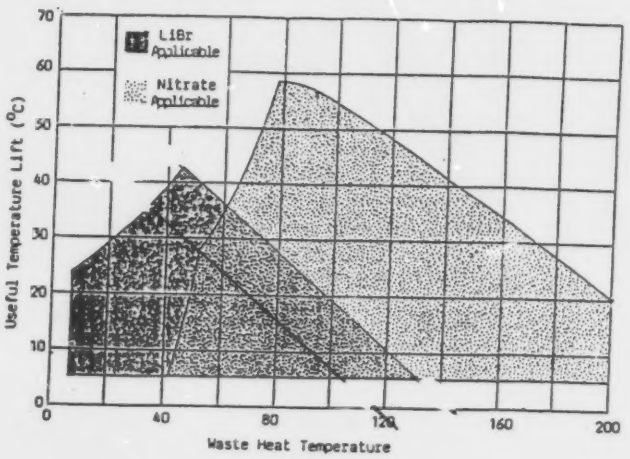
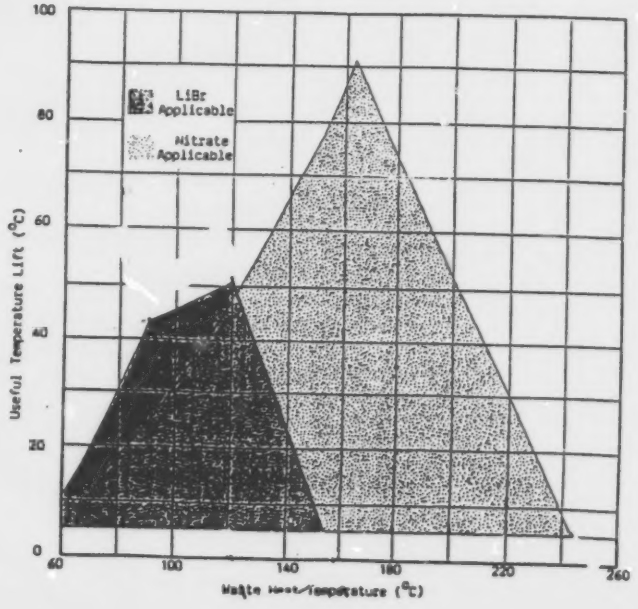


FIGURE 2

TEMPERATURE AMPLIFIER APPLICABILITY DIAGRAM



INTRODUCTION

Absorption heat pumping fundamentals are reviewed in past IETC proceedings (Erickson, 1983a).

This is the first published account of research performed by Energy Concepts Company for the Oak Ridge National Laboratory on developing a high temperature absorption working pair. Phase I of that research, the laboratory phase, had been completed and is summarized herein. The complete Phase I results will be available from NTIS (Davidson, 1986).

The tasks of Phase I were to screen and select an absorption working pair capable of operation up to 260°C, at high lifts, and with low cost metallurgy (preferably mild steel); to measure and analyze the thermodynamic, corrosion, and stability properties; and to calculate the predicted performance of an absorption heat pump incorporating the selected absorbent.

All tasks were completed successfully. Figures 1 and 2 summarize the new lift and temperature capabilities achieved.

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BACKGROUND

Large industrial and commercial scale absorption chillers came into widespread use about 35 years ago. In the last ten years, that same technology has been extended to heat pumping applications (all temperatures above ambient). However, the sphere of application of absorption heat pumping has remained extremely limited due to the temperature limitations of existing absorption working pairs.

Needed Temperature and Lift Capability

At any industrial or commercial plant site, there are usually at most two or three appropriate points at which heat pumping should be applied. Those points may be identified by "pinch" or "target" analysis (Duran, 1986). The temperature at that point, and the amount of temperature lift required to do heat pumping at that point, will vary widely from plant to plant and process to process. Thus a need exists for industrial scale heat pumps capable of operating at many different temperature levels and temperature lifts.

The above need has long been recognized by researchers in the absorption cycle field. The generally recognized limitations of the currently used $LiBr-H_2O$ absorption working pair are:

1) Maximum lift of 45°C, as determined jointly by limited solubility field and by corrosion (Erickson, 1985).

2) Maximum absorbent temperature of 170°C, based on corrosion rate of Cu-Ni or ferritic stainless steel.

3) No use of austenitic stainless steel due to halide stress corrosion susceptibility.

In 1982, at a conference convened to review the state-of-the-art of absorption working pairs, the continuing need for higher lifts and temperatures than those possible with $LiBr-H_2O$ was emphatically reiterated (Raldow, 1982).

Water as Working Fluid

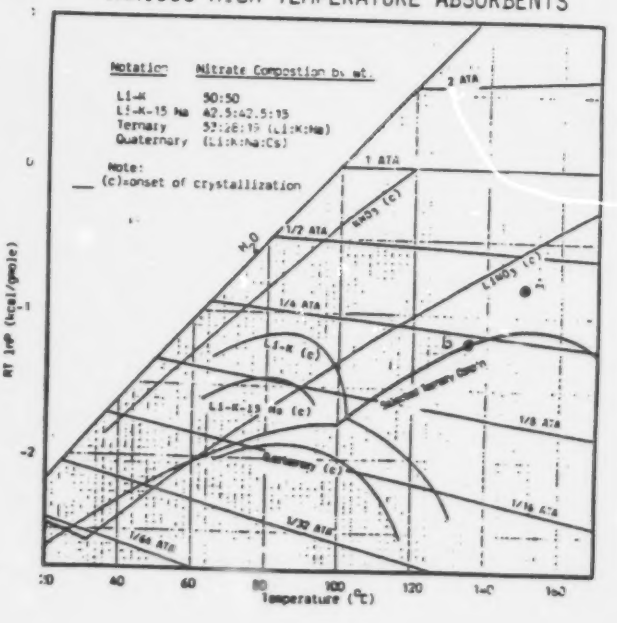
When dealing with absorption cycles which will pump heat from near or above ambient temperature, as opposed to refrigeration and air conditioning cycles, water has overpowering advantages as choice of working fluid. It has exceptionally high heat of evaporation, exceptionally high film heat transfer coefficient, very low viscosity, exceptionally low cost, and is safe, nontoxic, and nonflammable. Its only minor detractions are low pressure, high heat capacity, and potential corrosivity. Thus the real choice in the search for high temperature absorption working pairs reduces to selection of a suitable aqueous absorbent. The problem is to find an aqueous absorbent that allows full realization of the major advantages inherent to selection of water as working fluid, i.e., one which does not concurrently introduce too many or too severe offsetting disadvantages.

SELECTION OF ABSORBENT COMPOSITION

The water dissolving characteristics of the various pure alkali metal nitrates and several discrete nitrate mixtures are available in the literature. Analysis of the literature data reveals that none of the pure nitrates have an acceptable solubility field for an absorption cycle, nor do the $NaNO_3-KNO_3$ combinations. Some of the $LiNO_3-KNO_3$ or $LiNO_3-NaNO_3$ combinations have an acceptable high temperature solubility field, but their solubility at low temperatures is extremely limited.

Figure 3 was prepared from screening data using the assumption that all compositions tested had approximately equal slopes on the RTlnP vs. T plot. The crystallization lines illustrate the effect on the solubility field of varying the salt composition. Several ternary nitrate mixtures were tested, some allowing evaporator temperatures as low as 60°C.

FIGURE 3
CRYSTALIZATION LIMITS FOR
VARIOUS HIGH TEMPERATURE ABSORBENTS



Quaternary mixtures incorporating $CsNO_3$ can further decrease the evaporator temperature to 45°C. However, those mixtures have lower lifts and require more pumping power than the selected mixture, due to their lower $LiNO_3$ content.

A trade off, between acceptable evaporator temperature and achievable lift led to the final selection of 58 w/o (weight percent) $LiNO_3$, 28 w/o KNO_3, 19 w/o $NaNO_3$. This composition is believed to be most applicable for general purpose industrial use.

The onset of crystallization for this composition is shown in Figure 3. Note that for any system pressure above that which corresponds to a 68°C evaporator, higher solution concentrations (and higher temperature lifts) cannot result in crystallization. This is because the crystallization curve for the ternary nitrate bends downward with increasing temperature--the water vapor pressure approaches zero at the anhydrous melting point of 193°C.

The new absorbent has a wider solubility field than any of the nitrates pictured except the quaternary mix. It also has a favorable shutdown characteristic requiring dilution to only 42 w/o H_2O to remain liquid at 20°C. In contrast pure $LiNO_3$ must be diluted to 59 w/o H_2O at 20°C.

The costs of $LiNO_3$, KNO_3, and $NaNO_3$ respectively are \$2.75,\$0.40, and \$0.20 per pound. The cost of the ternary nitrate is one-third the cost of LiBr.

Two U.S. patents have been issued to Energy Concepts on this technology: U.S. Patent 4454724, which discloses mixtures including both nitrates and nitrites; and U.S. patent 4563295, which discloses the ternary alkali metal nitrate absorbent. One additional U.S. application is still pending.

MEASURED PROPERTIES OF THE SELECTED ABSORBENT

General

The thermodynamic properties of an absorbent which have greatest impact on the thermodynamic performance of an absorption cycle are the vapor pressure, the crystallization temperature, the specific heat. These were measured directly. Viscosity was also measured. All measurements were taken as a function of temperature and solution concentration. Much of this data is available on the individual alkali nitrates in the literature, but little or none is available on aqueous mixtures. Furthermore, the individual salts crystallize at much lower concentrations than do mixtures, so no data was available at the concentrations of interest and it was therefore necessary to measure the above parameters in laboratory experiments.

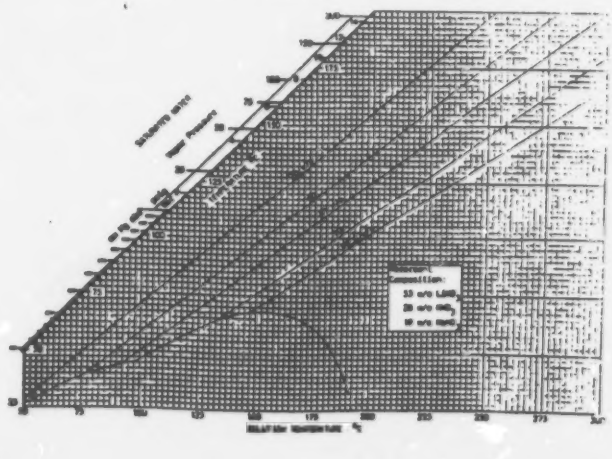
Vapor Pressure and Crystallization Temperature

The vapor-liquid-solid equilibrium pressure diagram of the working fluid with its absorbent is essential for evaluating the working fluid pair. It reveals what cycles are feasible, and it is the basis for calculating specific enthalpies and COP.

Vapor-liquid equilibrium (VLE) was measured for both subatmospheric and superatmospheric pressures. Glass apparatus was used for tests in the vacuum region so that liquid levels, boiling, and crystallization could be seen. A stainless steel pressure vessel was used for the high pressure measurements. The apparatus and procedure were verified against the vapor pressure curves of water and a LiBr solution.

Crystallization temperatures were obtained by incrementally adding distilled water to a molten solution of known starting composition, cooling slowly while stirring, and noting the temperature where cloudiness or precipitate first appeared. Usually at least 5 to 10°C additional cooling was possible before extensive slushiness was present. The crystallization temperatures were double-checked by incrementally increasing the concentration by boiling, and cooling the solution to crystllization from several boiling temperatures. The nitrate system never exhibited the subcooling which is frequently encountered with aqueous LiBr or alkali hydroxide systems.

The Duhring diagram is the most commonly used format for presenting VLE data for absorption systems. It plots absorbent temperature against



working fluid temperature for the same pressure. Figure 4 is the Duhring diagram for the high temperature absorption working pair (AWP). The onset of crystallization is also shown on this diagram.

Specific Heat

Specific heat measurements are necessary for calculating specific enthalpy and heat transfer behavior.

The specific heat of the absorbent was measured by calorimetry for 80 and 90 w/o concentration. All experiments were performed at atmospheric pressure. Therefore, measurements could be made only for temperatures between solidification and atmospheric boiling temperatures for each concentration.

The specific heat for the 80 w/o concentration was used to calculate specific enthalpy of the solution. A regression line through the data for 80 w/o concentration gave the following relationship:

Specific Heat (kJ/kgK) = 3.16 - 0.0077 x T(C)

Viscosity

Viscosity is the measure of a fluid's internal friction. It influences the amount of parasitic pump work required to maintain flow. More importantly, it influences heat transfer film coefficients for the high temperature absorbent. The viscosity measurements are used below to calculate Prandtl number, which is one determinant of film coefficients.

A Cannon-Fenske viscometer was used to measure kinematic viscosity. Densities were measured by recording weight and volume in a graduated cylinder immersed in the same temperature control bath. Dynamic viscosity is the product of kinemetic viscosity multiplied by density. Measurements were taken for four concentrations at temperatures ranging from just above liquidus to below atmospheric boiling point.

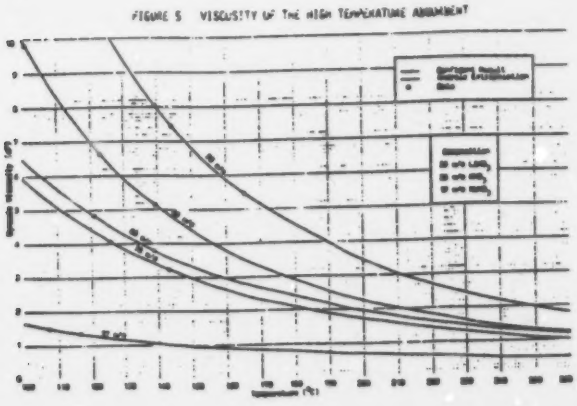


FIGURE 5 VISCOSITY OF THE HIGH TEMPERATURE ABSORBENT

Figure 5 presents the results for dynamic viscosity. Extrapolations follow the generally accepted Andrale relation.

ANALYTICALLY DERIVED PROPERTIES

Enthalpy

Specific enthalpy data facilitates energy balance and COP calculations. (See Coefficient of Performance, below.) The method used was that developed by Haltenberger (1959) and employed by McNeely (1979) for evaluating enthalpy of aqueous LiBr solutions. It relies heavily on steam table data, and requires specific heat data at only a single solution concentration. Briefly, the method uses the slopes of the constant concentration lines in the Duhring diagram. This slope is the ratio of two Clapeyron equations--one for the solvent and one for the solute, both at the same pressure. The only unknown in the resulting single equation is the latent heat of evaporation of the saturated solution. Subtracting this from the enthalpy of the superheated steam leaves the saturated liquid enthalpy of the solution. Haltenberger's approach is to analytically add and subtract water at constant temperature from a base concentration to generate enthalpy isotherms for varying concentrations. This is repeated for various temperatures using specific heat for a base concentration only.

Specific enthalpies calculated in this mannor were used to calculate cycle energy balances, discussed below.

Thermal Conductivity

Thermal conductivity strongly influences the heat transfer film coefficients. Accurate knowledge of this property is necessary for designing actual units, but contributes little in assessing cycle performance. Because of this it was only estimated from literature data for the Phase I research. Values have been reported in the literature for aqueous $NaNO_3$ and KNO_3--two of the ternary components--and also for several related salts. Most data was for 20°C, but temperature dependence was shown to be very slight and easily estimated.

Estimates were calculated for solutions in the following heat amplifier application: 260°C, 86.7w/o generator, and 154.5°C, 83.7w/o absorber. The results were 0.31 and 0.33 W/m^2K respectively.

These estimates contain a degree of conservatism due to the method of estimation. However, because they are eastmated values, not measured, a plus or minus 30 percent margin is suggested. Phase

II of this research will include direct measurement of the thermal conductivity of the high temperature absorbent.

Prandtl Number

Prandtl number is the ratio of momentum diffusion to thermal diffusion. It is the property which links the fluid velocity field with the temperature field in the convenctive film. This property appears in convective heat transfer relations for estimating film heat transfer coefficients.

Prandtl number is defined and calculated as the product of dynamic viscosity and specific heat, divided by thermal conductivity. The first two properties were measured, and the third estimated.

Absorption heat pumps (AHPs) are comprised essentially of heat exchangers. Six of the ten surfaces of a single stage absorption heat pump exchange heat with AWP fluids--two with pure water or steam, and the remaining four with the absorbent. Generator and absorber conditions represent the temperature extremes for the solution as well as the largest components in the solution loop. The solution exchanger experiances intermediate conditions. Therefore, the Prandtl number was calculated for generator and absorber conditions only. Operating conditions for the LiBr system were taken from a LiBr heat pump application, not a chiller. Operating conditions for the high temperature absorbent are postulated as typical for a high temperature heat pump, outside the range of LiBr capability.

Table 1 presents a comparison of Prandtl numbers calculated for typical LiBr and high temperaure absorbent applications. An average Prandtl number of 13 to 23 was calculated for the high temperature absorbent. This compares with 9.8 for LiBr. For the high temperature absorbent, a range is reported to account for a possible 30 percent error in the estimated thermal conductivity values. In heat transfer relations the Prandtl number is typically raised to the 1/3 power, diminishing the significance of these differences. (For equal Reynolds numbers, the high temperature absorbent would have a 20% greater Nusselt number.)

TABLE 1

HEAT TRANSFER PROPERTIES COMPARISON

	Lithium Bromide		High Temp. Absorbent	
	Solution in Generator	Solution in Absorber	Solution in Generator	Solution in Absorber
Typical Conditions:				
Temp. (°C)	160	93	260	134.5
Conc. (w/o)	65	61	86.7	83.7
Viscosity (cP)	2.1	2.5	1.5	3.8
Specific Heat (kJ/kgK)	1.8	2.0	1.8	2.1
Thermal Conductivity* (W/m²K)	.44	.46	.39 to .09	.33 to .10
Prandtl Number	8.6	11.	6.8 to 12	19 to 34
Average Prandtl Number	9.8		13 to 23	

* Estimated

CORROSION AND THERMAL STABILITY

The two properties addressed in this section are the reason that no other aqueous absorbent to date has successfully been extended to temperatures above about 180°C.

A mixture of approximately 60 w/o $NaNO_3$, 40 w/o KNO_3, known as draw salt, is marketed by several companies as a heat transfer fluid. It is rated as chemically stable up to 595°C (Olin, 1982). There are many instances of industrial use of this salt, for heat treatment as well as for heat transfer. An example of current interest is the Molten Salt Electric Experiment (Holmes, 1983), where 80,000 kg is used at 566°C to store solar energy.

The corrosion behavior of the anhydrous salt has been studied by both DuPont (Kirst, 1940) and by Sandia National Laboratories (Bradshaw, 1982). These references show stainless steels having corrosion rates of less than 1 mil per year at temperatures up to approximately the chemical stability limit, and mild steel at temperatures about 100°C lower. Also, the alkali metal nitrates are routinely added to aqueous systems as corrosion inhibitors, and $LiNO_3$ is specifically added to LiBr for that purpose.

Experiment

Both static isothermal and dynamic temperature cycling tests were conducted.

Two specimen geometries were used--flat plate and 0.5 inch OD tubing. The typical specimen was 9 inches long, and was immersed approximately three quarters in the absorbent.

The static isothermal tests were conducted in both SS 304 and Inconel 600 pressure vessels, 1 1/2 inch OD by 16 inches long. The solution depth was about 7 inches. A pressure gage was mounted on the vessel. These tests were conducted at various temperatures from 160°C to 310°C, and with various salt compositions, including aqueous $LiNO_3$ alone. The "blank" run, with no corrosion specimen present, was conducted in the Inconel vessel. The dynamic tests were conducted in a 4 inch by 26 inch SS 304 pressure vessel. It was mounted on a shaker, and the temperature continuously cycled from 260°C to 210°C and back at an hourly rate (one hour for each direction). Standard industrial grade alkali nitrate salts were used.

The generation of non-condensable gas was monitored over the period of the experiment. The apparatus was evacuated to less than 3 mm Hg absolute pressure at the start while cold, and then the vacuum was measured again while cold at the end. For some experiments, intermediate vacuums measurements were also taken.

Three materials were tested: mild steel (A36), stainless steel (304), and pack aluminized stainless steel. The latter has been found to be effective in resisting anhydrous nitrate corrosion at temperatures above 600°C. The weight change data are presented in Table 4.1, plus the calculated mil/year corrosion rate based on the weight change.

The rate of noncondensable gas generation in the blank run was 4 kPa pressure in 30 days, corresponding to .0018 moles of gas per year. The salt charge was 1.21 moles. Thus the indicated rate of decomposition of the absorbent at 315°C is approximately 0.15% per year.

Table 2 data shows temperature and $LiNO_3$ content to be the two significant factors in determining corrosion rate, with no apparent effect from water concentration. All of the corrosion rates are extremely low, well within routine industrial tolerance levels. The mild steel does experience noticeably higher corrosion rates than stainless steel, although still very low. As mentioned above, the amount of non-condensable gas generation is also very low, corresponding to the low corrosion rates. The non-condensable gas generated during the blank run was even lower, although it was not zero. It is not known whether the small amount observed was due to slight corrosion of the Inconel vessel or due to slight decomposition of the absorbent.

One of the mild steel tubing specimens in the cycling experiment was bent and stress loaded before exposure. It had the same resiliency and resistance to further bending after exposure as before, indicating no significant degree of preferential grain boundary attack.

The conclusions to be drawn from the above data are that all stainless steels, including austenitic varieties, are acceptable materials of construction over the entire temperature range; that mild steel is acceptable in absorbent contact areas over the entire temperature range, but should probably not be used in high temperature vapor phase areas (e.g., above 220°C); and that mildly alloyed steel, e.g., 2.5% Cr, will probably be adequately corrosion resistant in the vapor spaces.

TABLE 2 AQUEOUS NITRATE CORROSION TESTS

	Specimen Type	Material	Temperature °C	Duration Days	Sol'n Comp'n w/o	Test Pres. psig	Start Wt. gm	Weight Chg. gm	Noncondens. kPa	mil/year
STATIC	Flat	CS	230	27	Tern. 37 Li	13	73.2	-.02	8	N.C.
	Flat	CS	280	14	Tern. 37 Li	33	63.05	+.15	10	+
	Tube	CS	270	34	Tern. 41 Li	170	76.09	-.19	18	1.06
	Tube	CS	315	34	Tern. 41 Li	270	75.56	-.12	17	0.67
	Tube	Alon SS 304	260	24	$LiNO_3$		104.78	-.58	5	2.84
	Tube	Alon SS 304	260	25	Tern. 53 Li		104.78	+.02	5	+
	Blank		315	30	Tern. 53 Li	100	--	--	4	--
DYNAMIC	Tube	CS	260-210	67	Tern. 53 Li	60-10	218.7	-.02	--	N.C.
	Tube	CS	260-210	20			217.7	-.05	--	N.C.
	Tube	CS	260-210	67			216.95	0.00	--	N.C.
	Tube	CS	260-210	67			99.35	-.01	--	N.C.
	Tube	CS	260-210	67			305.55	0.00	--	N.C.
	Tube	SS 304	260-210	67			129.10	+0.34	--	+

+ = weight gain

N.C. = No significant change

ANALYSIS OF PERFORMANCE

The benefits of an absorption heat pump lie in fuel cost reductions for the user. These stem chiefly from the heat balance of the absorption cycle. Using the high temperature absorbent, new industrial applications of heat pumping involving much higher temperatures and significantly higher temperature lifts are possible. The cycle COP and the application temperatures are linked. For higher lifts slightly lower COPs result. This is due to sensible heat effects. Fortunately these effects are not severe, and they can be mitigated with minor additional component design. Another important point, not further treated herein is that the higher temperature energy savings are usually valued higher than the low temperature energy savings associated with present heat pumps.

In the discussion below, both high and low temperature scenario lift COPs are calculated for the new absorbent including comparison with LiBr.

Feasible Uses and Cycle Diagrams

For any absorption working pair, all feasible cycles can be revealed by careful inspection of the VLE diagram, such as Figure 4 for the high temperature absorbent. After determining all feasible cycles for a given absorbent the temperaure capabilities of those cycles can be summarized using the format of useful temperature lift vs waste heat temperature. Figures 1 and 2 were produced in that manner.

The following ground rules and assumptions were applied equally to both absorbents for deriving the applicability diagram:

- All heat exchangers have 5.56°C (10°F) LMTD;
- 3 w/o solution hysteresis;
- 15°C (27°F) margin against crystallization for both constant concentration cool-down and constant pressure heatup;
- 260°C nitrate solution temperature limit; and
- 170°C LiBr solution temperature limit.

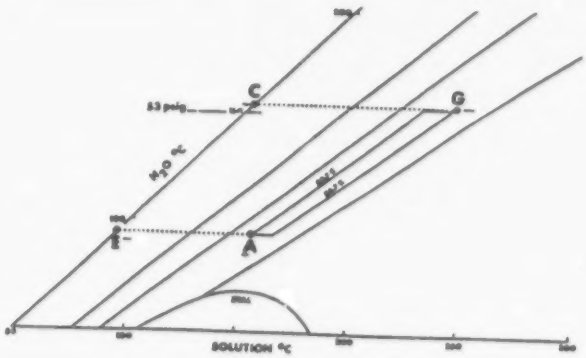
Figures 1 and 2 showed the results for heat amplifier and temperature amplifier modes respectively. Only single stage heat pumps are plotted because these are usually more economic. However, the high temperature capability of the ternary nitrate absorbent also makes possible 2-stage systems for lower lift heat pumping cases where LiBr can provide only a single stage.

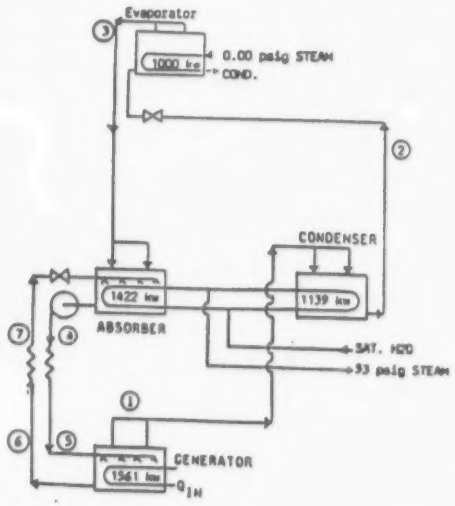
Coefficient of Performance

Energy balances were calculated for the example cycles depicted in Figures 6 and 7. This was done using the NBS Steam Tables (Haar, 1984), and solution specific enthalpies calculated as described above. The temperatures, enthalpies, and mass flow rates are shown on the figures.

FIGURE 6

HEAT AMPLIFIER WITH HIGH TEMPERATURE ABSORBENT





STREAM NO.	FLUID DESCRIPTION	TEMP. C	PRES. ATA	CONC. W/O %NaNO3	ENTHALPY KJ/kg	FLOW kg/s
1	STM. FROM GEN.	247.0	5.22	0.0	2949	0.496
2	WTR. FROM COND.	134.5	5.22	0.0	652	0.496
3	STM. FROM EVP.	95.0	.823	0.0	266.8	0.496
4	SOL. FROM ABS.	134.5	.823	83.7	341.0	14.33
5	SOL. TO GEN.	225.1	5.22	83.7	455.4	14.33
6	SOL. FROM GEN.	247.0	5.22	86.7	686.0	13.84
7	SOL. TO ABS.	164.5	.823	86.7	367.3	13.84

COP = 1.64

Figure 6 presents a thermodynamic cycle diagram and flowsheet for of a heat amplifier using the high temperature absorbent. This closed cycle heat pump produces 53 psig steam from atmospheric pressure waste steam, such as from a wort boiler at a brewery. In this example the generator temperature is set at 247°C. This heat pump could produce higher pressure steam from the same atmospheric waste steam if the generator temperature is increased.

Figure 7 presents a thermodynamic cycle diagram and flowsheet for a temperature amplifier using the high temperature absorbent. This absorption heat pump produces 600 psig steam from 100 psig waste steam. The condenser temperature is high enough to allow economic rejection of low grade heat to the atmosphere via fin tubes instead of adding burden to the cooling water utilities. This example demonstrates the extreme of high lift and high temperature capability. Note that for the same advantageous condenser temperature, 50 psig waste steam (147.5°C) can be raised to 250 psig steam (208°C or higher).

These flowsheets represent preliminary estimate designs; no attempt was made to optimize the design or to include sensible heat recovery from the working fluid as would be appropriate for high lift cases. The COP results are 1.64 for the HA case and 0.42 for the TA case. For high lift cases inclusion of two very small sensible heat exchangers increases the amount of useful heat delivered by approximately 6 percent.

COP Comparison With LiBr

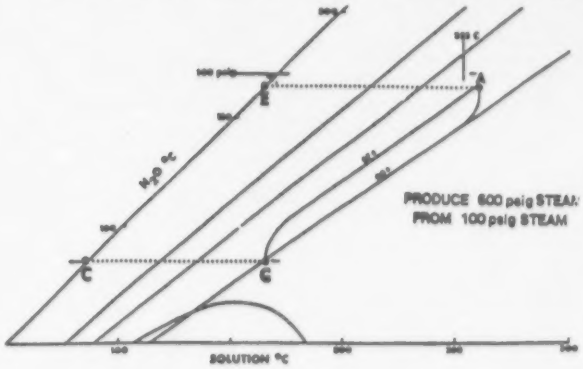
The high lift cases above cannot be achieved with LiBr. For a meaningful comparison with LiBr, a low lift, low temperature HA case was studied--one which is achievable with both LiBr and the high temperature absorbent. Two flowsheets were calculated--one for each absorbent. In each case the design parameters were identical. The calculated COP was 1.81 with LiBr versus 1.87 with the high temperature absorbent. The high temperature absorbent has a 3.3% higher COP than LiBr in the heat amplifier mode.

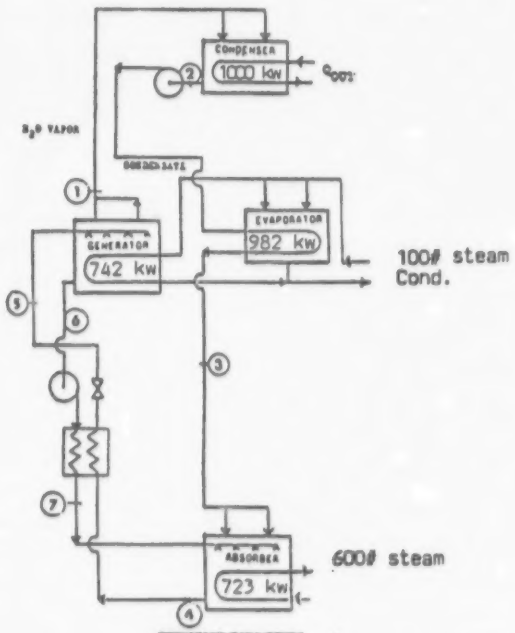
For another comparison with LiBr, a case with a useful temperature lift of 45°C (near the limit of LiBr capability) was calculated. Both COPs degenerated (without additional sensible heat exchangers), but the high temperature absorbent retained a 2.2 percent COP advantage.

These results are consistent with the fact that the high temperature absorbent exhibits less negative deviation from Raoultian behavior than does LiBr. As a general rule, for equivalent system designs, the heat amplifier COP using the high temperaure absorbent will be slightly better than that of LiBr in the same cycle

FIGURE 7

TEMPERATURE AMPLIFIER WITH HIGH TEMPERATURE ABSORBENT





OPERATING PARAMETERS

STREAM NO.	FLUID DESCRIPTION	TEMP. C	PRES. ATA	CONC. W/O SALT	ENTHALPY KJ/kg	FLOW kg/s
1	STM. FROM GEN.	164.4	.3933	0	2807	.409
2	WTR. FROM COND.	86.0	.3933	0	360	.409
3	STM. FROM EVP.	164.4	6.80	0	2763	.409
4	SOL. FROM ABS.	260.0	6.80	67	702	12.26
5	SOL. TO GEN.	176.4	.3933	67	583	12.26
6	SOL. FROM GEN.	164.4	.3933	90	571	11.85
7	SOL. TO ABS.	250.0	6.80	90	691	11.85

COP = .420

conditions. Correspondingly, the temperature amplifier COP will be slightly less than that of LiBr. The scale and temperature lifts of the new industrial applications now made feasible will often justify the addition of the small sensible heat exchangers noted above for enhanced COPs in both cycles.

SUMMARY AND CONCLUSIONS

A new aqueous absorbent has been identified which provides higher temperature capability (260°C), higher lifts, and use of lower cost construction materials, than current absorption heat pumps (e.g. those using $LiBr-H_2O$).

The high temperature absorbent is a ternary mixture of $LiNO_3$, KNO_3, and $NaNO_3$ in the preferred proportions of 53, 28, and 19 weight percent respectively. In addition to being thermally stable to well above 260°C, it promotes the formation of a passive and protective corrosion resistant oxide film on both mild steel and all stainless steels.

The thermodynamic, corrosion, and stability properties of the new absorbent have been measured. Additional properties have been analytically derived as necessary to predict the performance capabilities and limitations of an absorption heat pump using the new absorbent.

The high temperature absorbent is useful with waste heat temperatures in the range of 50 to 230°C for providing temperature lifts of up to 58°C for the HA (heat amplifier) mode and 90°C for the TA (temperature amplifier) mode. This contrasts to the LiBr capabilities of 5 to 150°C waste heat temperatures and respective lifts of 43°C and 51°C.

The new absorbent is not a panacea for all existing absorbent limitations. It cannot replace LiBr in air conditioning applications, nor NH_3-H_2O in refrigeration applications. Also, the high temperature absorbent will not replace LiBr in all industrial heat pumping applications. LiBr has unique temperature applicability areas. In the area where the capabilities overlap, tradeoffs must be considered.

The high temperature absorbent has a COP in the HA mode which is 2 to 3 percent higher and a COP in the TA mode which is a corresponding amount lower than that of LiBr. The high temperature absorbent will generally require a larger shutdown dilution system, but most materials of construction will be lower cost.

For higher temperatures or higher lifts, which are the applications of greatest interest to industry, the high temperature absorbent is the only viable absorbent identified to date. It greatly extends the temperature and metallurgical capabilities of absorption heat pumps. These new capabilities bring many important industrial applications within the scope of absorption heat pumping for the first time.

References

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APPENDIX - D

TECHNOLOGY TRANSFER AND HEAT PUMP DESIGN

SCREENING SUMMARY

Case	Description
I.	Degum overhead heat pumped to produce 50 psig steam.
I.a.	- via Type I AHP using 500 psig steam.
I.b.	- via Type II AHP using 27°C cooling water.
II.	Stripper overhead drives deprop. reboil. via Type I AHP using 50 psig steam.
III.	Degum overhead drives stripper reboil. via Type I AHP using 500 psig steam.

Case	UA	Savings (MM BTU/h)	Value ($/MM BTU)	(UA) ($/h)	Comment
I.a.	15.85	16.0	2.5	.396	500 psig steam
I.b.	4.45	6.72	2.5	.265	Small Scale
II	24.6	39.7	2.5	.248	300+ pipe feet
III	13.95	16.0	3.5	.249	+ note attached

Case III:
(Similar note would apply to Case I.a.)

AHP would be driven by 500 psig steam.

Stripper bottoms normally driven by 200 psig steam valued at $3.50/MM BTU.

AHP provides 1.72 BTU @ $3.50 for each BTU used @ $ X (value of 500 psig steam).

Actual savings = (QA + QC) 3.5 - QG x "X"

Where QG = generator input (500 psig steam) [BTU/h]
QA = absorber output [BTU/h]
QC = condenser output [BTU/h]
"X" = value of 500 psig steam [$/BTU]

Now QG = 22.22×10^6 BTU/h
QA = 20.17×10^6 BTU/h
QC = 18.05×10^6 BTU/h

If "X" = 5.00 $/MM BTU

Then Calculated Savings = 22.7 ($/h)

Actual Savings = [133.8 - 22.22 X] ($/h)

Conclusion

Steam pressures must be properly valued ($/BTU) in order to properly value Case III savings.

Case 1a

Refer to Figure I (This Appendix)

Generator: 500 psig steam = 243°C
Tg = 237°C
LMTDg = 6°C

Condenser: Tc = 153°C
50 psig steam = 147.6°C
LMTDc = 5.4°C

Evaporator: Te = 97.5, Tauhd: 120°C - 101°C
LMTDe = 11.23°C

Absorber: Ta = 155°C
50 psig steam = 147.6°C
LMTDa = 7.4°C

COP = 1.64 (from ICTC '86 paper)

QE = 16 MM BTU/h = savings

Output = 41 MM BTU/h

Notes: Savings will be diluted by use of higher value (500 psig) steam. See comment re Case III.

Case 1b

Refer to Figure I (This Appendix)

Generator takes first 6.89 MM BUT/h from Condensing Overhead

Generator:	Driven by overhead condensing at 120 - 113.6°C
	Tg = 107.5°C
	LMTDg = 8.92°C
Condenser:	Tc = 55°C
	C.W. = 27°C - 43.7°C out
	LMTDc = 18.4°C
Evaporator:	Te = 97.5°C
	Overhead curve: 113°C - 101°C (assumed straight)
	LMTDe = 8.06°C
Absorber:	Ta = 155°C
	50 psig steam = 147.6°C
	LMTDa = 7.4°C
COP	= .42 approximately (conservative, could be .44)
Saving:	Q Absorber is 6.72 MM BTU/hr.

Case II:

Refer to Figure II (This Appendix)

Generator: Driven by 50 psig steam = (147.6°C)
Tg = 140°C
LMTDg = 7.6°C

Condenser: Tc = 90°C
Deprop. Reboils at 81°C
LMTDc = 9°C

Evaporator: Driven by overhead condensing from 83°C - 64°C (assumed straight); (39.7 MM BTU/h)
Tevap. = 58°C
LMTDe = 13.3°C

Absorber: Ta = 92°C
Deprop. Reboils at 81°C
LMTDa = 11°C

Energy Balance Estimate:

$QE = 39.7$ MM BTU/h overhead duty (1)

$QA + QC = QG + QE$ 1st Luw (2)

$\frac{QA + QC}{QG} = 1.82$ COP for given lift (3)

$\frac{QC}{QE} = 1.053$ steam tables est. (4)

$QC = 41.795$

$$\frac{QG + QE}{QG} = 1.82$$

QG = 48.41 MM BTU/h

QA = 1.82 (48.41) - 41.795

QA = 46.32 MM BTU/h

QSUM = 39.7 MM BTU/h = savings

AHP Output = (QA + QC) = 88.1 MM BTU/h

Notes: Lithium - Bromide can do this in Type II mode, also 100M pipe needed.

Case III:

Refer to Figure III (This Appendix)

Note: AHP is in parallel with reboiler, takes 34% of b.p. to reboil.

Generator: Driven by 500 psig steam = 243°C
Tg = 237.5°C
LMTDg = 5.5°C

Condenser: Tc = 161.3°C
2nd part of boil-up curve: 140.9 - 159.4°C
LMTDc = 7.8°C

Evaporator: Overhead Cond. from 120°C - 101°C (assumed straight)
Te = 99.5°C
LMTDe = 5.46°C

Absorber: Ta = 150.7°C, drives 1st part of boil-up
Boil-up = 134 - 140.9°C
LMTDa = 12.9°C

Energy Balance Estimate:

COP = 1.72 from curve COP vs. Lift . (1)

$\underline{QC} = \underline{(2930 - 682)}$ steam tables (2)
QE (2674.8 - 682)
= 1.1281

QE + QG = QA + QC 1st law(3)

QE = 16.0 MM BTU/h given overhead (4)

QC = 18.05 MMBTU/h

$$\frac{QA + QC}{QG} = 1.72$$

$$\frac{QE + QG}{QG} = 1.72$$

$QE = (1.72 - 1)\ QG$

$QG = 22.22\ QG$

$QA = QG + QE - QC$

$QA = 20.17$ MM BTU/h

COP = 1.72 for this lift

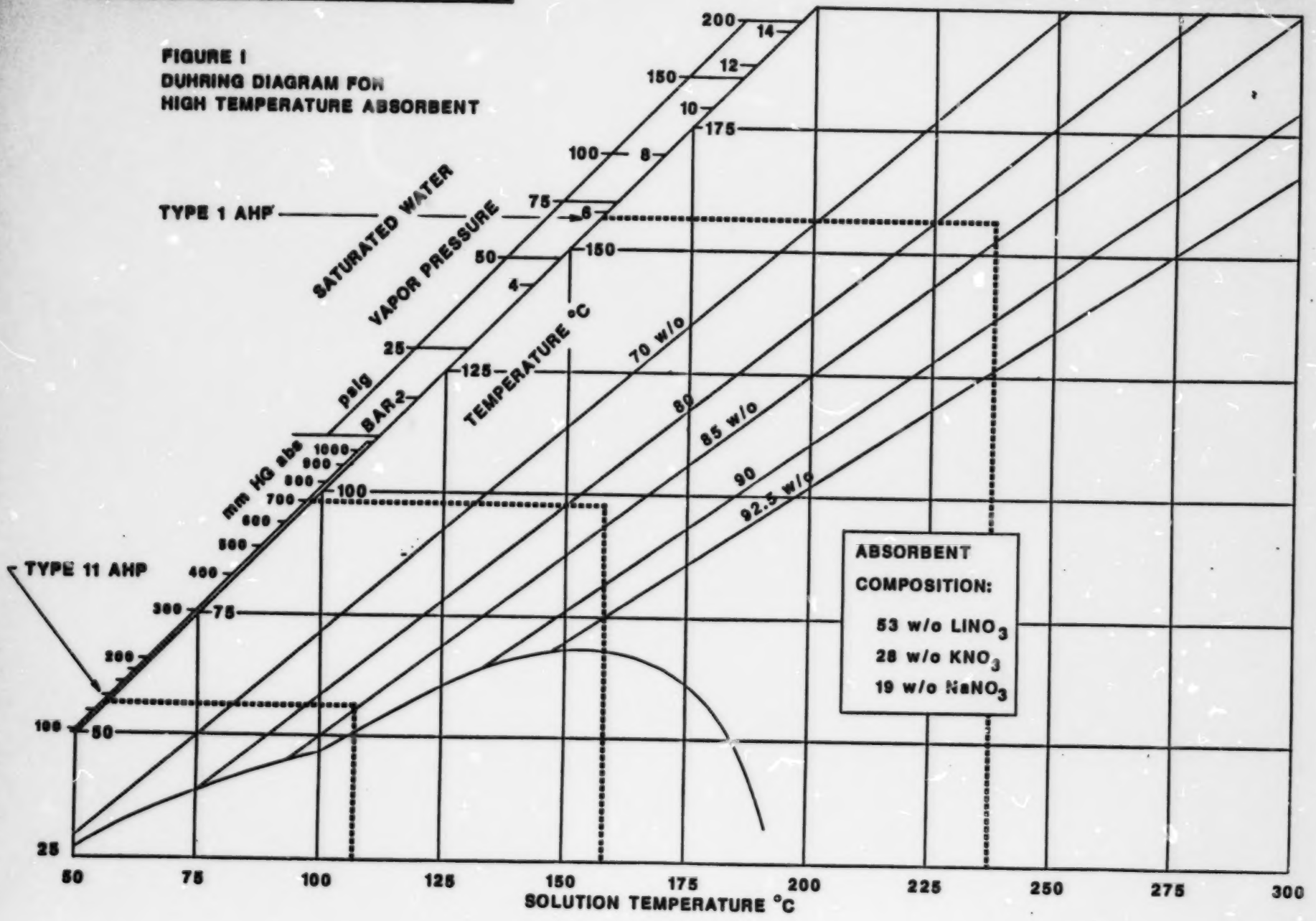
Output = 1.72 x 16.0 MM BTU/h = 27.52

Savings derive from Qevap. 16 MM BTU/h.

CASE I: DEGUM OVHD – 50lb STEAM

CHEMICAL HEAT PUMP STUDY

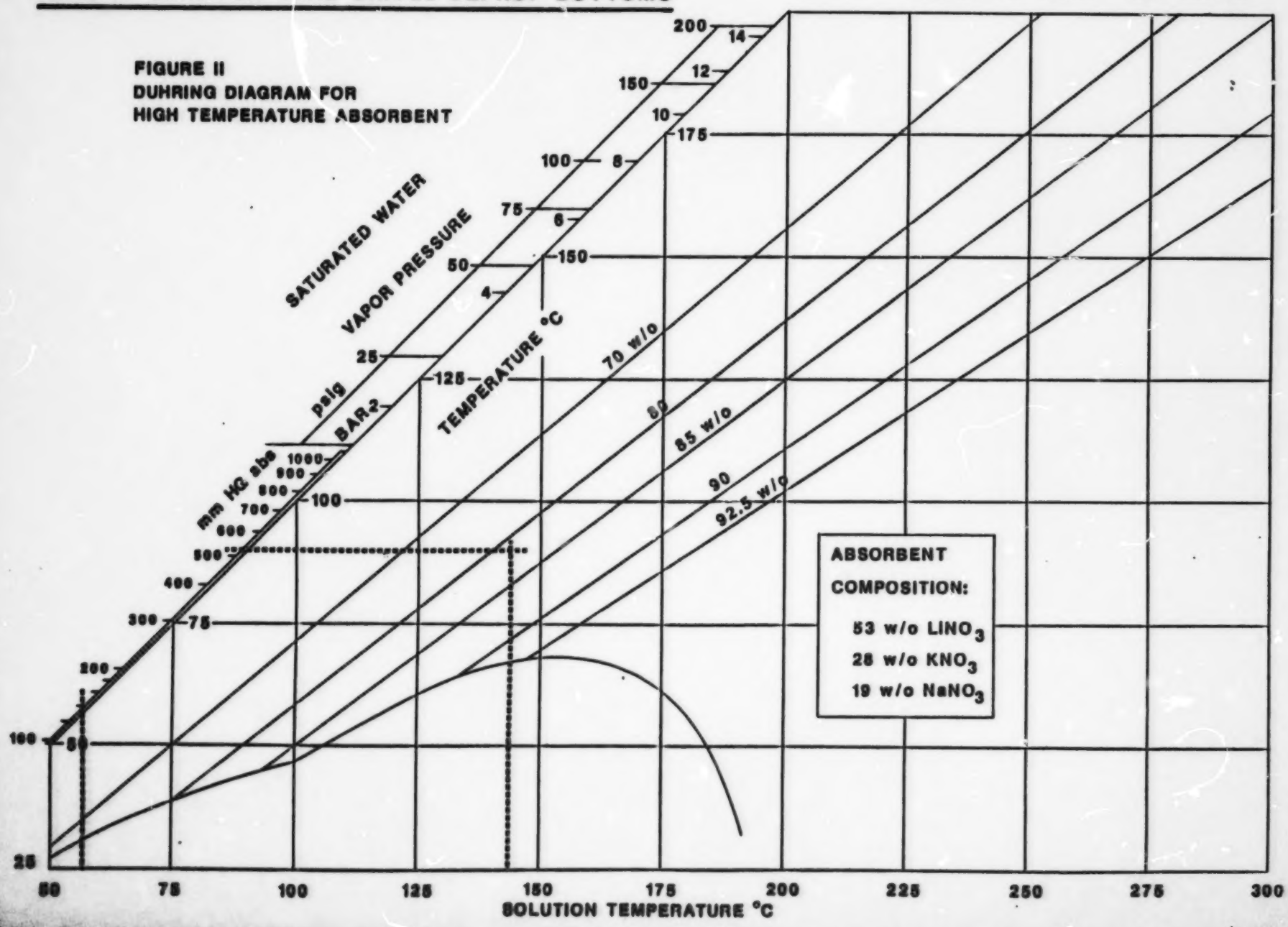
FIGURE I
DUHRING DIAGRAM FOR
HIGH TEMPERATURE ABSORBENT



CASE II: STRIPPER O'HD DRIVES DEPROP BOTTOMS

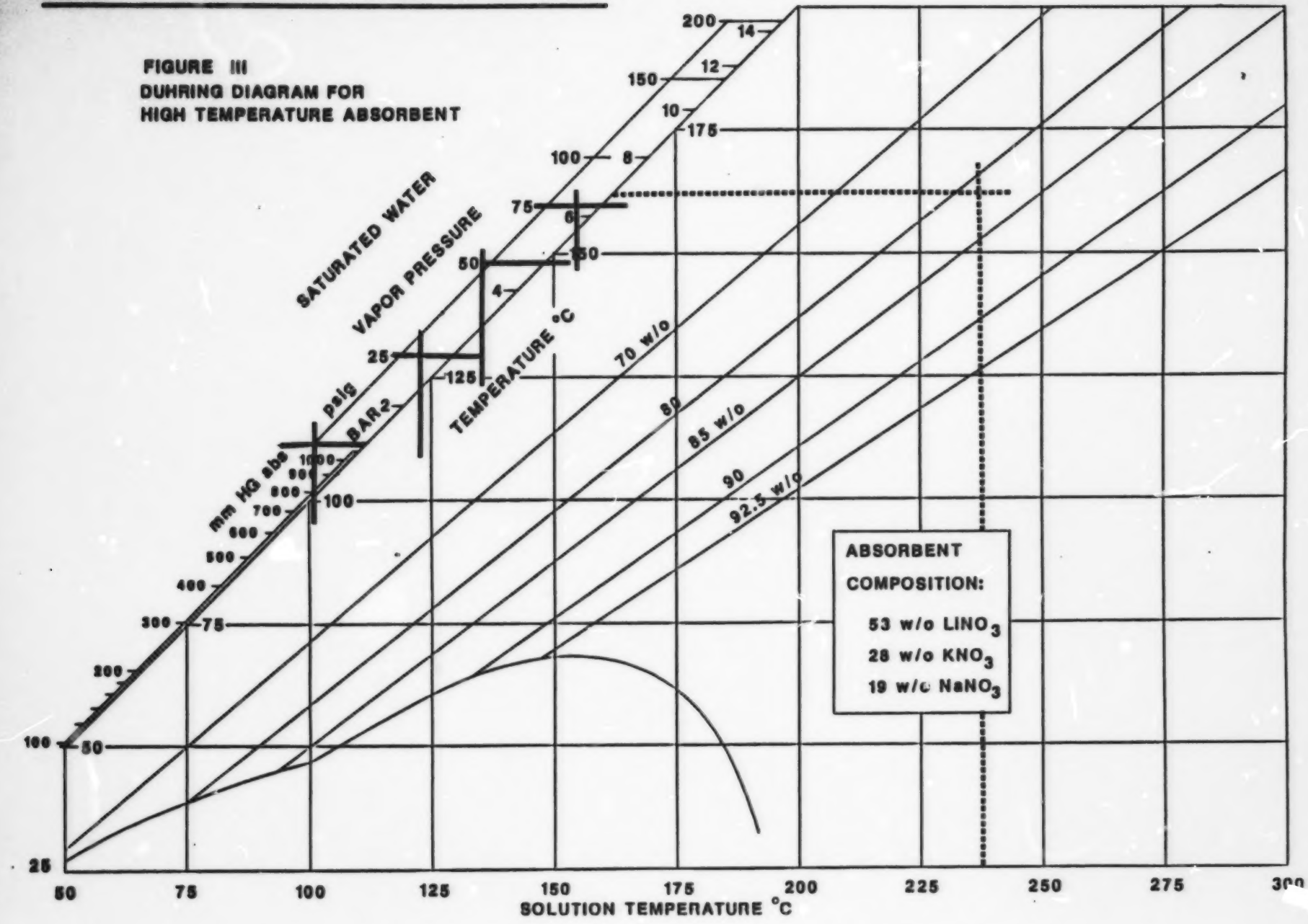
CHEMICAL HEAT PUMP STUDY

FIGURE II
DUHRING DIAGRAM FOR
HIGH TEMPERATURE ABSORBENT



CASE III: DEGUM OVHD – STRIPPER BOTTOMS

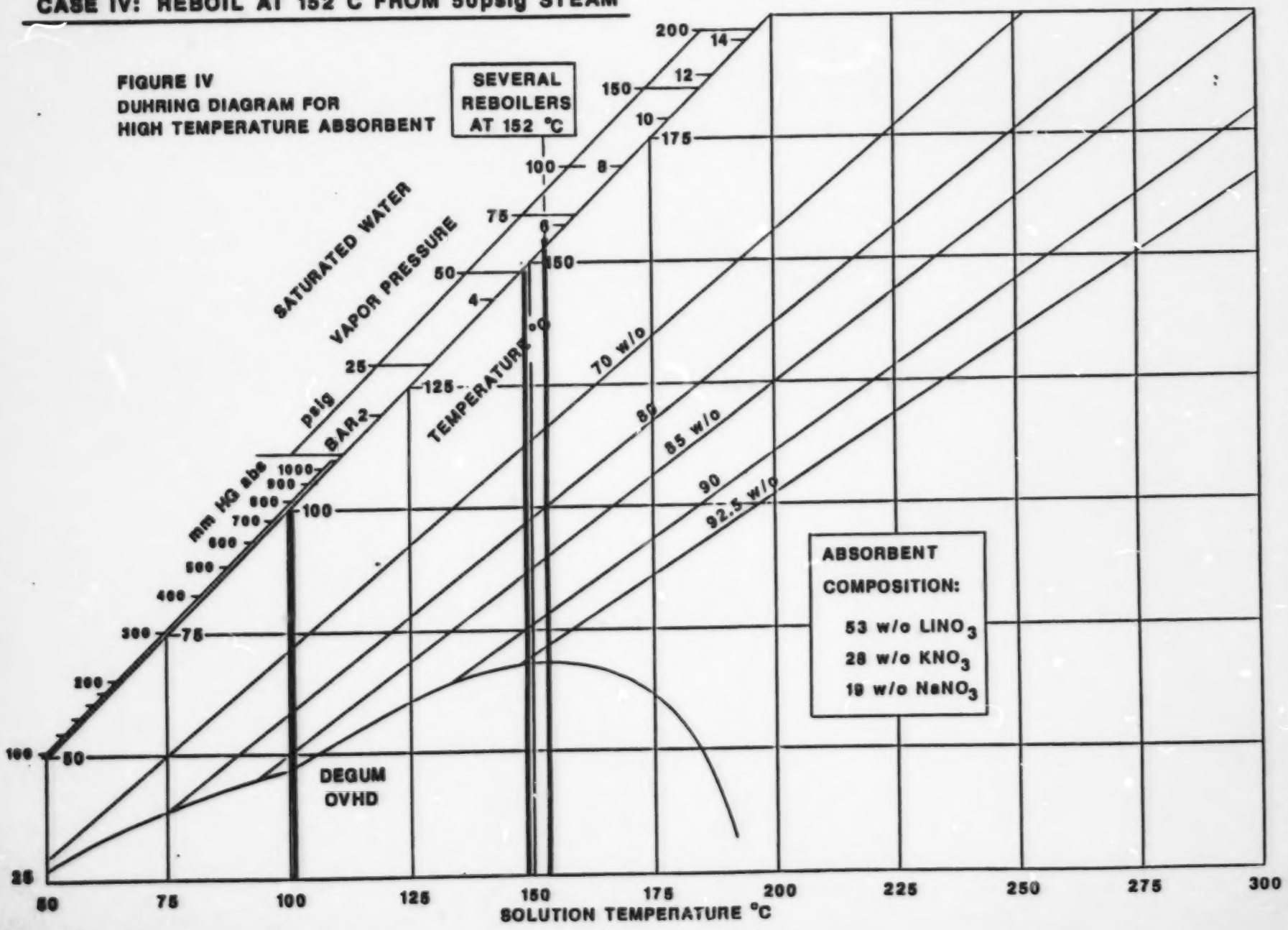
FIGURE III
DUHRING DIAGRAM FOR
HIGH TEMPERATURE ABSORBENT



CASE IV: REBOIL AT 152 C FROM 50psig STEAM

CHEMICAL HEAT PUMP STUDY

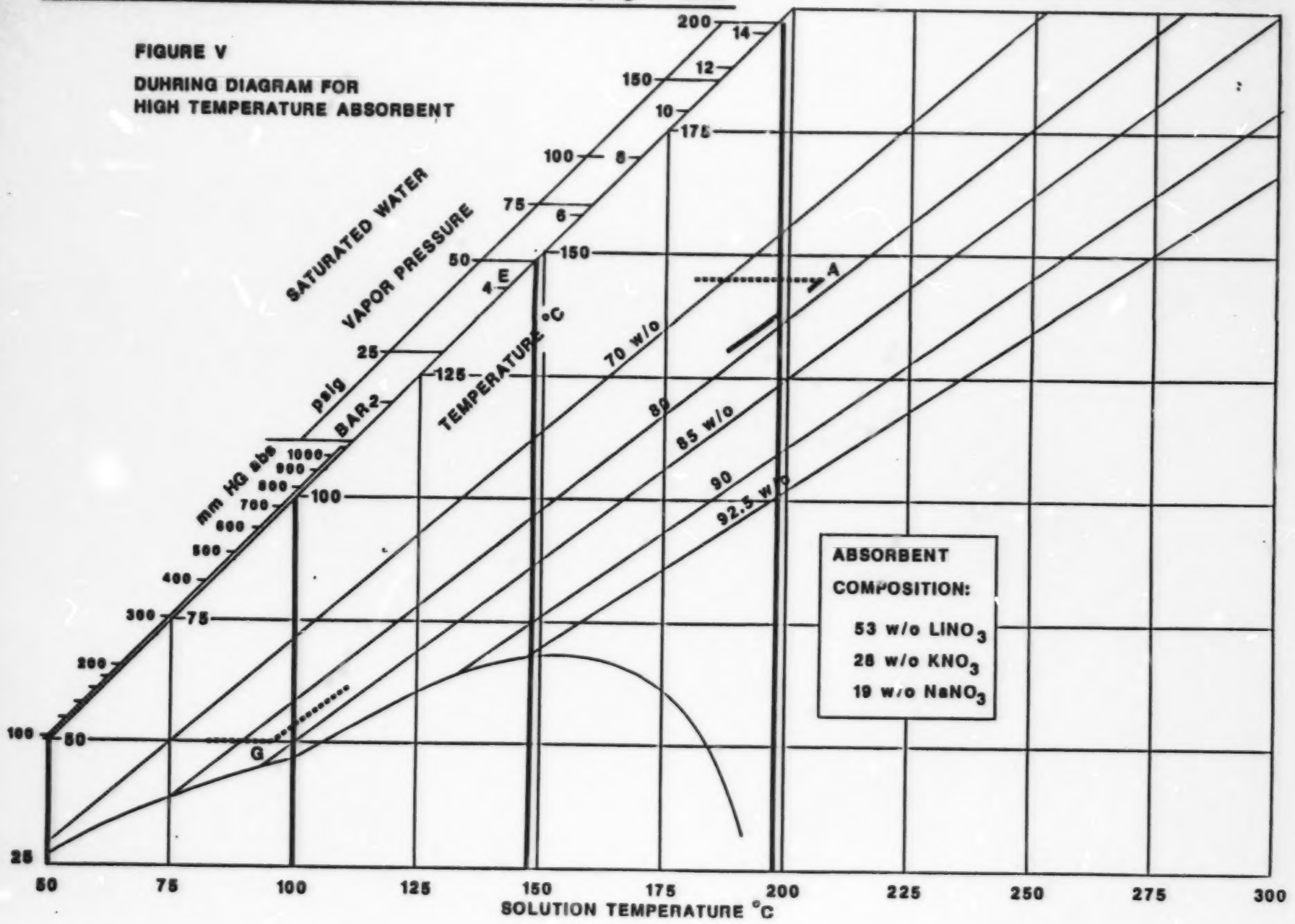
FIGURE IV
DUHRING DIAGRAM FOR
HIGH TEMPERATURE ABSORBENT



CASE V: PRODUCE 200psig STEAM FROM 50psig STEAM

FIGURE V

DUHRING DIAGRAM FOR
HIGH TEMPERATURE ABSORBENT



APPENDIX - E

HEAT PUMP INQUIRY

EQUIPMENT DATA SHEET

Client: Polysar (Corunna) Project: Chemical Heat Pump

1. ECC/Litwin to provide appropriation level estimate(+/-5%) for Case III - Degum Overheads drives Stripper Reboiler using high temperature absorbent.
2. Degum Overhead Condenser:
   - Duty = 8.0 MM Btu/hr.
   - U value = 30.3 Btu/hr.sq.ft.deg.F
   - Fouling Factors = 0.002(s/s), 0.001(t/s)
3. Cooling Water Temperature in/out = 27 deg.C /43.7 deg.C(max)
4. Stripper Reboiler:
   - Temperature in/out = 134 deg.C/159 deg.C
   - U value = 143 Btu/hr.sq.ft.deg.F
   - Fouling Factors = 0.0005(s/s), 0.002(t/s)
5. Design Conditions:
   - Degum Tower: 30 psig/ FV
   - Stripper Tower: 40 psig
   - HP Steam: 550 psig
   - Cooling Water: 90 psig
6. Union labels from UA and IBEW required.
7. All items detailed in Stearns Catalytic inquiry 2494-1 Supp#2 dated August 20, 1986 not revised above apply.

ENERGY CONCEPTS CO.
827 Ridgely Ave. Annapolis, Md. 21401 • 301/266-6521

February 2, 1987

Canatara Engineering Ltd.
P.O. Box 442
Sarnia, Ontario N7S 7J2

Attention: P. Cullen

Reference: Department of Supply & Services
Chemical Heat Pump Study Phase 2
Appropriation Heat Pump (AHP) Estimate

Dear Pat:

Energy Concepts Co. and Litwin Engineering are pleased to respond to your request for continued assistance on the referenced project. Our previous work has been reviewed and upgraded to a ±5% appropriation level budget estimate based on Canatara Engineering's Equipment Data Sheet dated 1/13/87, Stearns Catalytic's Inquiry 2494-1, and discussions with you.

The preliminary design for the above AHP utilizes Energy Concepts Co.'s high temperature absorbent (HTA) in a forward cycle Litwin Industrial Temperature Booster (ITB) as given below:

Exchanger	Stream	Temp. °C	Duty MM BTU/Hr.
Absorber	Stripper Btms	134-147	11.481
Condenser	Stripper Btms	147-159	9.138
Evaporator	Degum OH	120-101	8.000
Desorber	500 Psig/Stm	243	12.622

A preliminary P&ID for the referenced project and a typical ITB layout drawing is enclosed for your additional information.

The appropriation level budget estimate for the AHP described above is $843,100 (U.S.). This includes one skid-mounted AHP complete with all equipment, piping, instrumentation and electrical systems. All major equipment and fabrication will be performed in Canada. The estimate does not include field installation, interconnecting lines and tie-ins or modifications to the existing process unit.

We appreciate the opportunity to work with you on this project. If you have any questions or need additional information, please call.

Very truly yours,

William F. Davidson

William F. Davidson
Project Manager

Encl.

APPENDIX - F

HEAT PUMP COST ESTIMATE

CANATARA ENGINEERING LTD.

CODE:SUMMARY SHEET PROJECT ESTIMATE PAGE NO:01
CLIENT:DSS/EMR REV:01 DATE:87.03.09

DESCRIPTION	COSTS
Material	534405
Sub-contracts and Shop Labour	451795
All risk Insurance,Liability,Etc	1500
Federal Tax	0
Provincial Tax	0
TOTAL MATERIAL,SUBCONTRACTS,SHOP LABOUR	987700
Field Labour	0
Payroll Burden	0
TOTAL FIELD LABOUR	0
Field Supervision	14000
Field Office Personnel	8400
Field Cost Control,Planning	0
Construction Equipment,Tools	47050
Consumables,Small Tools	0
TOTAL OTHER FIELD CHARGES	69450
TOTAL HOME OFFICE EXPENSES	131740
SUB-TOTAL	1188890
Overhead	0
Fee	60000
TOTAL CHARGES	1248890
Contingencies	60000
Escalation	0
GRAND TOTAL	1308890

NOTES: 1)Estimate +/- 10%
2)No escalation is included as the project is not definite
3)An adder of $208,000 required for Polysar(Corunna) case

CANATARA ENGINEERING LTD.

CODE:SUB-SUMMARY PROJECT ESTIMATE PAGE NO:02
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	MATERIAL	LABOUR	SUBCONT
0100	Fired Heaters,Boilers	0	0	0
0200	Stacks	0	0	0
0400	Reactors & Internals	0	0	0
0500	Towers & Internals	0	0	0
0600	Heat Exchange Equipment	327550	0	18000
0700	Cooling Towers	0	0	0
0800	Vessels,Tanks,Drums & Internals	16310	0	6200
0900	Pumps & Drivers	5100	0	700
1000	Blowers & Compressors	1500	0	700
1100	Elevators,Material Handling Equip.	0	0	0
1200	Misc. Mechanical Equipment	0	0	0
2500	Tankage	0	0	0
2800	Filters & Centrifuges	0	0	0
2900	Agitators & Mixers	0	0	0
3000	Scrubbers & Separators	0	0	0
3100	Machine Tools,Equipment	0	0	0
3200	HVAC Equipment,Dust Control Equip.	0	0	0
3	Package Equipment	0	0	0
	SUBTOTAL-MAJOR EQUIPMENT	350460	0	25600
1300	Piping	93000	0	95500
1400	Sewers	1500	0	3500
1500	Instrumentation	27940	0	16415
1600	Electrical	19455	0	18680
1700	Concrete	0	0	40000
1800	Structural Steel	41250	0	73250
1900	Fireproofing	0	0	43900
2000	Buildings	0	0	0
2100	Site Developement	0	0	300
2200	Insulation	0	0	118800
2300	Painting	0	0	9100
2400	Field Testing	800	0	6750
2600	Catalyst,Chemicals	0	0	0
2700	Piling	0	0	0
3300	Fire Protection	0	0	0
	SUBTOTAL-BULK ITEMS	183945	0	426195
	TOTALS	534405	0	451795

CANATARA ENGINEERING LTD.

CODE:0600-HEAT EXCHGRS PROJECT ESTIMATE PAGE NO:03
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION		SIZE	MATERIAL	LABOUR	SUBCONT
0601	E-101A/B	Evaporator-BKU	48/60x192	60700		3500
	E-102	Absorber-BEM	45x240	47900		3000
	E-103	Recuperator-NEN	18x480	104750		4500
	E-104	Desorber-BEM	48x240	58700		3500
	E-105	Condenser-BEM	48x240	55500		3500
	TOTALS			327550	0	18000

File: DSS.estimate Page 1

CANATARA ENGINEERING LTD.

CODE:0800-VESSELS,TANKS PROJECT ESTIMATE PAGE NO:04
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION		SIZE	MATERIAL	LABOUR	SUBCONT
0801	D-102	Solution Drum	2-0 x 2-6	3890		800
	D-103	Air Separator	1-6 x 2-6	3233		800
	D-104	Solution Accum	2-0 x 2-6	4384		800
	D-105	Refrig Accum	2-6 x 2-6	4303		800
	FA-3109	Degum O'head	New 8"noz	500		3000
	TOTALS			16310	0	6200

CANATARA ENGINEERING LTD.

CODE:0900-PUMPS,DRIVERS PROJECT ESTIMATE PAGE NO:05
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION		SIZE	MATERIAL	LABOUR	SUBCONT
0901	P-103	Dilute Soln Pump	3x4-13	5100		700
	TOTALS			5100	0	700

CANATARA ENGINEERING LTD.

CODE:1000-COMPRESSORS PROJECT ESTIMATE PAGE NO:06
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION		SIZE	MATERIAL	LABOUR	SUBCONT
1001	P-104	Vacuum Pump	14ACFM	1500		700
	TOTALS			1500	0	700

CANATARA ENGINEERING LTD.

CODE:1300-PIPING PROJECT ESTIMATE PAGE NO:07
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1301	Bare Pipe-CS	27.06T	22520		
1302	Valves-CS		18180		
1303	Fittings-CS		21930		
1304	Shop Fabrication	12.90T	28770		
1307	Field Erection	27.06T			92500
1310	Temp Services		1600		3000
	TOTALS		93000	0	95500

CANATARA ENGINEERING LTD.

CODE:1400-SEWERS PROJECT ESTIMATE PAGE NO:08
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1401	Modify Existing 15" Sewer	20 LF	1500		3500
	TOTALS		1500	0	3500

CANATARA ENGINEERING LTD.

CODE:1500-INSTRUMENTATN PROJECT ESTIMATE PAGE NO:09
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1511	Control Valves	6 off	8970		
1521	Flow Elements	1 off	500		
1531	Flow Transmitters	29 off	13340		
1572	Controllers,Panel	31 off	5130		
		67 total			16415
	TOTALS		27940	0	16415

CANATARA ENGINEERING LTD.

CODE:1600-ELECTRICAL PROJECT ESTIMATE PAGE NO:10
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1601	Motor Starters,Instr Panel		4780		1200
1602	Power Wiring		6875		8880
1604	Grounding System		2000		2000
1605	Switchgear	575V/100A	3600		1200
1607	Instrument Wiring		200		400
1610	Tempory Power & Lighting		2000		5000
	TOTALS		19455	0	18680

CANATARA ENGINEERING LTD.

CODE:1700-CONCRETE PROJECT ESTIMATE PAGE NO:11
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1715	E-101A/B Evaporators	-			
	E-102 Absorber	6 CY			6000
	E-103 Recuperator	-			
	E-104 Desorber	7 CY			7000
	E-105 Condenser	-			
	D-102 Solution Drum	-			
	D-103 Air Separator	-			
	D-104 Solution Accum	-			
	D-105 Refrig Accum	-			
	P-103 Dil Soln Pump	-			
	P-104 Vacuum Pump	-			
	Excavation	80 CY			1600
	Concrete Footings	21 CY			24500
	Backfill-Granular B	46 CY			900
	TOTALS		0	0	40000

CANATARA ENGINEERING LTD.

CODE:1800-STEEL PROJECT ESTIMATE PAGE NO:12
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1801	E-101A/B Evaporators	7500 lbs	12250		14250
	E-102 Absorber	-			
	E-103 Recuperator	-			
	E-104 Desorber	-			
	E-105 Condenser	-			
	D-102 Solution Drum	-			
	D-103 Air Separator	-			
	D-104 Solution Accum	-			
	D-105 Refrig Accum	-			
	P-103 Dil Soln Pump	-			
	P-104 Vacuum Pump	-			
1805	Structural Steel-pipe supp	8500 lbs	17000		17000
1806	Steel-Shoes,clamps etc	4000 lbs	12000		12000
1800	Structural Steel-Skid	20000 lbs			30000
	TOTALS		41250	0	73250

CANATARA ENGINEERING LTD.

CODE:1900-FIREPROOFING PROJECT ESTIMATE PAGE NO:13
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
1901	E-101A/B Evaporators	270 CY			23100
	E-102 Absorber	-			
	E-103 Recuperator	-			
	E-104 Desorber	-			
	E-105 Condenser	-			
	D-102 Solution Drum	-			
	D-103 Air Separator	-			
	D-104 Solution Accum	-			
	D-105 Refrig Accum	-			
	P-103 Dil Soln Pump	-			
	P-104 Vacuum Pump	-			
	Structural Steel-Piperack	260 CY			20800
	TOTALS		0	0	43900

CANATARA ENGINEERING LTD.

CODE:2100-SITE DEV PROJECT ESTIMATE PAGE NO:14
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
2100	Grading-3/4 clear stone	15 CY			300
	TOTALS		0	0	300

CANATARA ENGINEERING LTD.

CODE:2200-INSULATION PROJECT ESTIMATE PAGE NO:15
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
2201	E-101A/B Evaporators	4.5"Fglas			8000
	E-102 Absorber	4.5"Fglas			3200
	E-103 Recuperator	4.5"Fglas			8500
	E-104 Desorber	4.5"Fglas			3200
	E-105 Condenser	4.5"Fglas			3200
	D-102 Solution Drum	4.5"Fglas			1000
	D-103 Air Separator	4.5"Fglas			1000
	D-104 Solution Accum	4.5"Fglas			1000
	D-105 Refrig Accum	4.5"Fglas			1500
	P-103 Dil Soln Pump	-			
	P-104 Vacuum Pump	-			
	Piping				88200
	TOTALS		0	0	118800

CANATARA ENGINEERING LTD.

CODE:2300-PAINTING PROJECT ESTIMATE PAGE NO:16
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
2301	Piping	27.05T			5400
	Structural Steel	12.25			3700
	TOTALS		0	0	9100

CANATARA ENGINEERING LTD.

CODE:2400-FIELD TESTING PROJECT ESTIMATE PAGE NO:17
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
2401	Piping-Hydrostatic Testing		800		6750
	TOTALS		800	0	6750

File: DSS.estimate Page 1

CANATARA ENGINEERING LTD.

CODE:SEE BELOW PROJECT ESTIMATE PAGE NO:18
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	DESCRIPTION	SIZE	MATERIAL	LABOUR	SUBCONT
3701	Licences,DOL Fees		1000		
3704	Safety Equipment		400		700
3706	Clean Up-Final		200		2240
3707	Site Office Charges		1000		
3710	Surveying		1000		
3700	TOTALS		3600		2940
6001	Field Supervision-Salaries			10000	
6002	-Payroll Burden			4000	
6011	Field Office Pers-Salaries			6000	
6012	-Payroll Burden			2400	
6500	Construction Equipment		30250		
	Construction Tools		16800		
	TOTALS		47050	22400	0

CANATARA ENGINEERING LTD.

CODE:7000-HOME OFFICE PROJECT ESTIMATE PAGE NO:19
CLIENT:DSS/EMR REV:01 DATE:87.03.09

CODE	JFC	DESCRIPTION	HOURS	RATE	COST
7000	070	Process Eng'g	500	30	15000
	080	Flowsheets	100	15	1500
	100	Site Development			0
	110	Concrete	250	20	5000
	120	Steel	325	20	6500
	130	Mechanical Eng'g	200	25	5000
	131	Vessel Design	200	23	4600
	132	HVAC			0
	141	Piping Design	700	20	14000
	143	Checking	60	20	1200
	150	Electrical	100	25	2500
	190	Instrumentation	125	22	2750
	240	Model Design			0
	301	Project Eng'g			0
	310	Tech Clerical	300	8	2400
	340	Eng Clerical	200	8	1600
		ENGINEERING TOTAL	3060		62050
	510	Project Mang't	200	30	6000
	530	Planning & Sched	50	25	1250
	540	Estimating			0
	550	Cost Control	100	25	2500
	580	Proj Clerical	100	8	800
		PROJECT TOTAL	450		10550
	610	Buying	320	25	8000
	630	Expediting			0
	640	Invoice Approval			0
	650	Shop Inspection	140	20	2800
	671	Purch Clerical	120	8	960
		PURCHASING TOTAL	580		11760
		Travel & Living	**********		2000
		Communications	**********		200
		Reproduction	**********		2000
		Computer Charges	**********		500
		Purchased Eng'g	**********		500
		Services Total			5200
		Home Office Total	4090		84360
		Overhead Fee @ %	*********	50	42180
		TOTAL			131740

APPENDIX - G

RETURN ON INVESTMENT

Introduction

The following bases are used in the calculations below:

- Steam Costs - typical for 600 psig/520°F = $5.50/1000 lbs.

- Electrical Costs - typical for SW Ontario
  = $0.0213/KWH usage
  = $9.24/KW/month demand

Typical Petrochemical Data

i) **Steam**

Steam Costs - 500 psig (H = 1204 BTU/LB) = $5.35/1000 lbs.
- 200 psig (H = 1199 BTU/LB) = $5.33/1000 lbs.

Steam Saved - 200 psig saved in Reboiler = 11.481 + 9.138 MM BTU/h
= 24600 LBH
= $131.12/hr.

Steam Used - 500 psig used in Desorber = 12.622 MM BTU/h
= 16800 LBH
= $89.88/hr

Net Steam Savings = $41.24/hr

ii) **Electrical**

Electrical Costs - 42 KW used = $0.89/hr usage
= $0.54/hr demand
= $1.43/hr total

iii) **Return On Investment**

Installed Cost	= $1,308,900
Payout based on 8400 hours operation/year	= 3.9 years

APPENDIX - H

COST COMPARISONS

A cost comparison between the Chemical Heat Pump used in this study is made with a Mechanical Heat Pump installed in 1980 at Dome Petroleum Ltd. at their Sarnia, Ontario site.

The Dome heat pump equipment cost and installed cost factor is extracted from the Cost Analysis Report herein and used to determine an installed cost. The project installed cost thus calculated is then factored down to the subject study size by using the well known 0.6 index, and then escalated according to the CE Plant Cost Index listed monthly in Chemical Engineering, published by McGraw-Hill.

Polysar (Corunna) Data

Process heat recovered	= QA + QC
	= 11.481 + 9.138 MM BTU/hr
	= 20.619 MM BTU/hr
Driver heat (500# steam)	= 12.622 MM BTU/hr
Coefficient of Performance (COP)	= 1.63
Installed Cost Estimate	= 1.309 MM

Dome Petroleum Data

Process heat recovered	= 35 MM BTU/hr
Driver power (electric)	= 2500 hp
COP	= 5.50
Equipment cost (heat pump only)	= $1.039 MM
Installed cost factor	= $21.558/$5.039 MM
	= 4.28
Escalation index for 1980	= 261.2
Escalation index for 1987	= 320
Installed cost in 1987	= $1,039*4.28*320/261.2
	= $5.448 MM

Installed cost at study size	= $5.448*(20.619/35)^6$
	= $4.966 MM

Cost Comparison

Mechanical/Chemical cost ratio	= $3.966/1.309 MM
	= 3.03

Mechanical Heat Pump Payout

Electric Power used at study size	= 20.619 MM @ COP of 5.5
	= 1098 KW
Electric power costs - usage	= 1098*0.0213
	= $23.39/hr
- demand	= 1098*9.24/720
	= $14.09/hr
- total	= $37.48/hr
200 psig steam saved	= 20.619 MM @ $5.50/1000 lbs.
	= $135.49/hr

Utility savings = $98.00/hr

Payout = 4.85 years

APPENDIX I

TECHNOLOGY TRANSFER BENEFITS

In an attempt to quantify the benefits to Canadian Industry where the Chemical Heat Pump gains wide acceptance, an assumption is made that 50% of the amenable energy conservation applications available in the petrochemical industry are viable and proceed to construction.

The amenable energy conservation applications in the petrochemical industry are based on Polysar (Corunna)'s 200 psig steam balance and ratioed to the Canadian market based upon relative crude oil feedstock rates.

Polysar (Corunna) Data

200 psig steam consumption	410,000 LBH
200 psig steam saved (study)	24,600 LBH
Crude feedstock	2,300,000 LBH
Installed cost for study	$1.3 MM

Canadian Data

Canadian crude oil intake	185,000 m^3/d Oilweek, 87.02.16
	17,020,000 LBH
Canadian amenable market	$1.3*(17.0/2.3)*410/24.6
	$160 MM
Canadian likely market	$80 MM